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# EXPERIMENTAL RESEARCHES;

## CHEMICAL AND AGRICULTURAL.

SHEWING

## CARBON TO BE A COMPOUND BODY,

## MADE BY PLANTS,

AND

## DECOMPOSED BY PUTREFACTION.

BY ROBERT RIGG, F.R.S.

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# INTRODUCTION.

The greater part of the natural productions which surround us, and which minister to our wants and enjoyments, are presented to us, not ready fitted for our purposes, but rather with a capacity of being adapted to our use. The beasts of the forest, and the wild fruits of the earth, would afford only a precarious subsistence for a few savage tribes. It is to the research, the intelligence, and industry of man, that nature yields up her treasures, and discovers her resources.

The wants of increasing numbers, no doubt soon taught mankind this lesson, and still urged them on at every step of their advance in the arts and sciences, in agriculture and manufactures. And as the pressure of numbers has not ceased, so neither are the resources of Nature exhausted. From our present position, we see new fields of discovery extending before us; and his labours are as valuable as ever, who brings to light new facts, or elicits new principles.

Among the sciences which have arisen in the progress of civilization, and which have so vastly accelerated its advances, Chemistry occupies a distinguished place. Its powers of analysis, of scrutinizing the properties, proportions, and combinations of matter, renders it invaluable in every branch of physical science. Of late years, these powers have been directed to researches into the economy of vegetation, and the decomposition of vegetable bodies; researches, of obvious importance to agriculture, and to the various arts and manufactures in which vegetable matter is employed. As yet, however, vegetable chemistry has made so little progress, that when we "consider the lilies of the field, how they grow," we must confess that we know little of the matter, beyond those facts which may be learned by attentive observation, without the aid of chemical science.

We know that seeds when placed in the earth, supplied with water, and kept at a proper temperature, germinate and grow into plants; that these plants exhibit certain prominent features in the economy of their vegetation, which are common to them all; for instance, that they appropriate water to their own purposes, and are influenced in their growth and development by change of temperature, difference of soil, and exposure to the light of the sun. But to convince us how superficial this knowledge is, it is only necessary to enquire how this water is appropriated by the plants; how their growth is affected by variety of temperature and soil, or by what process from the shapeless and buried seed, is developed the symmetry of the plant, and the beauty of the flower.

Again, we know that during the process of decomposition, many changes take place in animal and vegetable matter, and a variety of new bodies are formed, but we soon come to a stand-still, when we attempt to investigate the method and origin of these changes.

These enquiries are too interesting, and too important to be abandoned. But it is vain to attempt to form theories upon the principles of vegetation, or upon the changes which vegetable matter undergoes during decomposition, with the scanty information we possess of the habits of plants, and of the bodies of which they are composed. Theories so formed may be amusing, but they cannot be satisfactory.

We must begin with a minute, patient, and long-continued observation of the phenomena which plants exhibit, and a strict analysis of their component parts; and having thus enlarged our basis, and multiplied our materials, we may proceed to build up our theories with better prospect of success.

Under this conviction, I have for many years employed myself in these *Experimental Researches,* the results of which I now venture to lay before the Public. In prosecuting these Researches, I have found it to be of the utmost importance not to allow any thing to escape observation and attention, on account of its seeming insignificance. I think that greater errors have arisen from the neglect of what appear to be small things, than from any other source. Strictly speaking, there are no small things in Nature's laboratory,—they are all in their respective places indispensable; and we should probably be doing well, if in the analyses, and other examinations of vegetable matter, we were to suspect a more subtle and efficacious quality in those parts which appear least, when weighed and measured, and to attribute to them functions not less important, than those of their more weighty or bulky companions. For example: suppose a natural product to consist of four different elements, one of which bears a proportion of 70 per cent.; another, of only one in a thousand to the weight of the whole; the latter minute element will be found as essential as the other to the existence and character of the compound. In such a case, it is evident, that any theories upon the formation, the constitution, or the decomposition of such natural product, formed without reference to this one-thousandth part, are worse than useless, as being mere false lights upon the paths of science.

The labours of some distinguished chemists have been rendered abortive, by their allowing analogy to supply the place of induction, and by a disposition to speculate beyond what is warranted by experiment, or can be reconciled with practical experience.

I particularly refer to Professor Liebig's organic chemistry in its application to agriculture and physiology. It is much to be regretted that this celebrated writer had not examined more carefully those experiments from which he has drawn his conclusions relative to the economy of plants and the decomposition of organic matter. A more minute examination of these experiments, or one made with a sprig of mint grown in water, or a few seeds of wheat planted in moist barren earth, and kept in a limited atmosphere, would have furnished him with abundant proof that almost every leading principle which he has attempted to establish in that part of the book, which has reference to the physiology of plants, is erroneous. And an experiment, examined in all its parts, on the putrefaction of almost any kind of organic matter; or, a critical examination of those to which he has referred, would have satisfied him that he had not data to support his theories upon the changes which occur during the decomposition of organic bodies.

Many of the experiments given in Parts I. and II. relating to the compound nature of carbon, were brought forward in the year 1840. But at that time certain plausible theories were in vogue, with which many chemists were so satisfied for a while, as to think further experiment unnecessary. I trust the time has now arrived when experiment, and theory, will resume their proper places.

In conducting my experimental investigations, I have made my experiments with apparatus of the simplest kind; and, excepting an excellent balance, and about 30 pounds of mercury, the cost did not exceed a few shillings. The value of experiments in this branch of science, does not depend so much upon complicated and expensive apparatus, as upon a judicious adjustment of very simple means, and accuracy in manipulation.

That the information derived from my researches might have a practical as well as a chemical application, I have generally made such experiments as had either directly, or indirectly, an application to agriculture, to the arts, or to manufactures.

The principle upon which I conducted my experiments, was, to allow nature to do her work; and during her process, as well as after its termination, to examine, to the best of my ability, every feature which presented itself.

In order to make these examinations more complete, I resolved the organic matter into carbon, hydrogen, oxygen, nitrogen, and ashes, by a mode of analysis which combines simplicity with accuracy, and which has been of the greatest service to me in the course of my investigations.

By adopting this mode of research, we not only obtain a great variety of facts, from which to draw our conclusions, but we also acquire a practical acquaintance with the subject matter of our research, and the best manner of dealing with it, as a valuable companion in our very intricate and hidden path.

In these researches I have met with evidence the most conclusive, that many of the bodies which have hitherto been regarded as simple are really compound, and that instead of having from fifty to sixty ultimate elements, the number of these bodies is, in all probability, very small.

If experimental investigations, pursued for more than twenty years, have taught me one thing more than another, it is, that we have yet a great deal to do in the critically experimental part of organic chemistry; and that before we can properly speculate (excepting to a very limited extent) upon the changes which occur in organic matter, and especially upon those which take place in plants during their growth, and their putrefactive fermentation, we must first master the analysis of miasm, a form of matter which has hitherto proved too subtle for our most delicate examinations.

In writing out my experiments, some of which have been under observation for several years, I have endeavoured to give a plain statement of facts as they occurred; and if in so doing, I have, in some instances, been guilty of repetition, I must ask the reader's indulgence.

Some experiments are given with very minute detail, because their results, being opposed to existing theories, they will probably be subject to severe scrutiny. With each experiment is generally given the method which I adopted in making it, so that future experimentalists may test the accuracy of my results, either by that or some other method of their own.

The calculations have been made with great care, and I trust that no material error will be found in them.

In that part of my work which relates to the origin of carbon, I have occasionally referred to the experiments of other persons, and especially to those made by M. De Saussure, in order to shew that other experiments besides my own warrant the conclusions which I have drawn.

If these researches should be instrumental in placing the science of organic chemistry, in its application to agriculture, to the arts, and to manufactures, on the solid basis of experimental evidence, I shall not regret the time and labour bestowed upon them.

ROBERT RIGG.

*Greenford, Middlesex,*
*Dec.* 1843.

# CONTENTS.

## PART I.

Page

CARBON A COMPOUND BODY MADE BY PLANTS IN QUANTITIES VARYING WITH THE CIRCUMSTANCES UNDER WHICH THEY ARE PLACED :—

Carbon .......... 1
On the production of carbon by plants .......... 3
Carbonic acid one source of carbon .......... 8
Of fertile land .......... 13
Of inferior land .......... 17
Of bad land .......... 19
Of meadow land .......... 22
Evidence in support of carbon being derived from the atmosphere .......... 30
Production of carbon by plants .......... 60
Plants impart to the air more carbon than they receive from it 74
Plants do not increase their quantity of carbon when carbonic acid is removed from the atmosphere in which they grow .. 81
Influence of carbonic acid in the atmosphere upon the growth of plants .......... 87
Increase of carbon in plants is not equal to that which disappears from the atmosphere .......... 91
What becomes of the carbonic acid which disappears from the atmosphere during the growth of plants .......... 101
The carbonic acid which proceeds from combustion .......... 112
The carbonic acid given off by animals during respiration and perspiration .......... 113
Carbonic acid given off during fermentation and the decay of organic matter .......... 115
Carbonic acid given off from volcanoes, fissures of the earth, and water springs .......... 116
The proportions in which plants make carbon under various circumstances .......... 120

Plants make carbon differing in proportions with the earths in which they grow ........ 128
The quantity of carbon produced by plants varies with the quantity of earth in which they grow ........ 143
The quantity of carbon made by plants is influenced by temperature ........ 146
The quantity of carbon made by plants is influenced by miasm 149
The quantity of carbon made by plants is influenced by saline and earthy bodies ........ 168
The quantity of carbon made by plants is influenced by carbonaceous matter left in the earth by other plants ........ 172
The quantity of carbon made by plants is influenced by the water supplied to them ........ 175

# PART II.

## DECOMPOSITION OF CARBON DURING THE PUTREFACTIVE FERMENTATION.

Putrefactive fermentation ........ 186
Signs of the decomposition of carbon during the putrefactive fermentation ........ 186
The volume of carbonic acid ........ 189
Soluble matter formed during the putrefaction of vegetables.. 191
Theory of the putrefactive fermentation ........ 209
Carbon disappears when seeds germinate and grow in a confined atmosphere ........ 217
Carbon disappears when mixtures of organic matter undergo putrefaction ........ 227
Carbon disappears during the putrefaction of seedling plants.. 232
Carbon disappears when fruit undergoes putrefaction ...... 235
Carbon disappears during the putrefaction of herbaceous plants 238
Carbon disappears when seeds from whence oils have been expressed undergo putrefaction ........ 244
Carbon disappears when fermented liquors undergo the putrefactive fermentation ........ 248

# EXPERIMENTAL RESEARCHES,

## &c. &c.

### ERRATA.

Page 128, line 15, *for* 47, *read* 168.
255, — 15, *for* 7, *read* ·7.

## CARBON.

Carbon, until lately, has been regarded by chemists as an ultimate element,—a body which has hitherto resisted all attempts to decompose it. It is extensively diffused throughout the universe. In the diamond it is present in its purest state. It abounds in the earth, in combination with lime and oxygen, forming limestone. When similarly combined, it forms a part of all shells. Carbon, when combined with oxygen, forms a component part of the atmosphere. In this gaseous state it is held in solution in land and sea water. Carbon is an essential constituent in all animal and vegetable matter. This body, when elaborated under the economy of the living animal or plant, is considered as an organized product. It is then in combination with hydrogen, oxygen, and, in most instances, with small portions of nitrogen and alkaline, and earthy bodies; as will be better illustrated in the following analyses, which represent the constitution of the different substances in their natural state.

| | | | |
|---|---|---|---|
| Lean Beef . . . . | Carbon . . . . | 14·4 | |
| | Hydrogen . . . . | 8·6 | |
| | Oxygen . . . . | 72·1 | |
| | Nitrogen . . . . | 4·5 | |
| | Ashes . . . . . | ·4 | |
| | | | 100 |
| The solid fat part of Beef . . . . . | Carbon . . . . | 66·95 | |
| | Hydrogen . . . . | 10·06 | |
| | Oxygen . . . . | 22·84 | |
| | Nitrogen, not determinable | | |
| | Ashes . . . . . | ·15 | |
| | | | 100 |
| Oak, recently felled | Carbon . . . . | 42·40 | |
| | Hydrogen . . . . | 6·30 | |
| | Oxygen . . . . | 50·44 | |
| | Nitrogen . . . . | ·16 | |
| | Ashes . . . . . | ·70 | |
| | | | 100 |
| Oak Leaves . . . | Carbon . . . . | 9·47 | |
| | Hydrogen . . . | 9·84 | |
| | Oxygen . . . . | 78·72 | |
| | Nitrogen . . . | ·95 | |
| | Ashes . . . . . | 1·02 | |
| | | | 100 |
| Common Grass, not free grown . . . | Carbon . . . . | 3·61 | |
| | Hydrogen . . . . | 10·32 | |
| | Oxygen . . . . | 85·11 | |
| | Nitrogen . . . . | ·44 | |
| | Ashes . . . . | ·52 | |
| | | | 100 |
| Wheat Seeds, Husks, and Kernel, as carried from the field | Carbon . . . . | 36·9 | |
| | Hydrogen . . . . | 7·2 | |
| | Oxygen . . . . | 53·2 | |
| | Nitrogen . . . . | 1·1 | |
| | Ashes . . . . . | 1·6 | |
| | | | 100 |
| Turnip Bulb, from the field . . . . | Carbon . . . . | 4·25 | |
| | Hydrogen . . . . | 10·50 | |
| | Oxygen . . . . | 84·79 | |
| | Nitrogen . . . . | ·41 | |
| | Ashes . . . . . | ·05 | |
| | | | 100 |

| | | |
|---|---|---|
| Cabbage Leaves, four days gathered . . | Carbon . . . . | 4·29 |
| | Hydrogen . . . | 10·59 |
| | Oxygen . . . . | 84·04 |
| | Nitrogen . . . . | ·34 |
| | Ashes . . . . . | ·74 |
| | | ——100 |

These analyses convey a general idea of the chemical constitution of animal and vegetable substances in their natural state. The proportionate quantity of carbon varies considerably. Thus, lean beef contains 14·4 per cent., and the fat of beef 66·95. Oak recently felled contains 42·4; oak leaves, 9·47; common grass, not free grown, 3·61; wheat seeds, from the field in their ripe condition, 36·9; turnip bulb, from the field, 4·25; cabbage leaves, four days gathered, 4·25.

## ON THE PRODUCTION OF CARBON BY PLANTS.

In prosecuting an inquiry into the sources from whence plants derive their carbon; an element, which forms about 40 per cent. of the weight of dry vegetable matter, we shall briefly notice, in the first place, some of the leading facts or results with which the agriculturist is practically acquainted; and afterwards call in the aid of chemistry to assist us in drawing correct conclusions, as to the principle upon which these facts or results depend.

It is well known that some kinds of land yield more produce to the farm-stead than others; it is equally impressed upon the mind of the agriculturist, that the less fertile land is made more productive by the addition of manure, lime, various kinds of salts, &c. While the more productive land is kept in good condition, and affords many successive crops without its produce being returned to it; the less fertile requires to be supplied, in some instances, not only with *organic* matter* originally produced by itself, and subsequently modified by the different processes to which it has been subjected, but also with that which has been derived from other sources. If this more productive land do not remain in its generative condition at the termination of a long lease, it may be brought to a highly productive condition by slight addition of manure, or other organic matter, or by one year's fallow. But to bring the less fertile land to a highly generative condition, very large quantities of organic matter are required to be carried to it every year, or, at farthest, every two years.

This contrast between the productive and less fertile land, cannot have escaped the commonest observer of agricultural phenomena; and although *he* may not have speculated much upon the cause of such dissimilarity, yet every inquiring agriculturist must have felt disposed to ask the question—Whence arises this increased quantity of vegetable matter, which grows upon, and is carried off some land, year after year, and which so greatly exceeds the amount of dry vegetable matter returned to it, without any apparent deterioration in the quality or condition of the soil?

From whence do some of our productive lands receive that food for the plants which they produce year after year, for ten, twenty, or even a greater number of years successively, without any extraneous supply of organic matter, and while only fallowed every fifth, seventh, or tenth year?

From whence do some strong clayey lands receive the carbonaceous matter which is contained in their annual crops, and how are they kept in the same fertile condition, when the only substance carried to them in five years, which contains carbon, does not comprise more of this material than the crop of one year?

---

* That part of animal and vegetable matter which disappears by the ordinary processes of combustion, is regarded in this inquiry as *organic* matter. The ashes which are left, the earths, and other incombustible bodies, as *inorganic*.

From whence are pasture lands supplied with materials for those vegetable productions on which cattle subsist and fatten, without any other supply of either animal or vegetable matter to them than that which the cattle themselves furnish, the land being found at the end of ten, twenty, or thirty years to be more productive than at first, although it has furnished large quantities of plants every year, the materials of which have undergone animalization, and have been so carried off?

On the other hand, what becomes of all that organic *matter* which is carried year after year to the less fertile and barren soils, and which, in the quantity of its carbon, exceeds that which was carried from them in the form of white and green crops?

Another question is not less frequently put, viz., How do lime and several salts, which contain no carbonaceous matter, or bone-dust, &c. which contains very little of this substance, act in making land more productive?

In investigating this subject I shall first describe some experiments which generally admit of a practical application; and then proceed to give an account of other experiments, which to a certain extent enable us to account for some of the phenomena, which are constantly taking place in our fields and gardens.

By ultimate analysis we are enabled to discover with great accuracy the weight of *carbon* in the organic matter contained in any soil, and in the vegetable matter produced by the soil. As to the organic matter (manure) carried to any soil, our best experiments can only approximate to the quantity of carbon contained in it, on account of the difficulty experienced in obtaining it in a uniform and dry state.

The first experiment to be described was made upon stiff soil from Surrey, composed of equal parts of light blue clay and silicious sand lying upon a clayey subsoil. It had uniformly four white crops and three green in seven years, each crop yielding from two and a half to three tons of dry vegetable matter per acre. The quantity of dry organic matter laid upon the land during the seven years, was equivalent to the matter produced by it in two years. Proper attention having been paid to keep this land clean, it was, at the expiration of each seven years, as capable of producing plants as at the commencement.

This land was ploughed from four to six inches deep, and when the soil lay in the state of compactness in which the plants grew, its weight upon the subsoil was from $\frac{1}{5}$ to $\frac{1}{6}$ more than the same bulk of water.

On subjecting an average sample of this soil in its dry state to ultimate analysis by means of oxide of copper, I obtained results which gave for the soil in its vegetating state of moisture 2·15 per cent. of its weight of carbon, and ·28 per cent. of its weight of nitrogen.

On making calculations for this land six inches deep, and lying upon the subsoil, not as a compact solid mass of earthy matter, but, as above stated, a soil pervious to air and water, and in a condition suitable for the germination of seeds, and the growth of plants, we find an acre to weigh 1,599,000 pounds, which would contain 34,378 pounds of carbon at the rate of 2·15 per cent. of its weight.*

On taking the produce at 2¾ tons (6,160 lbs.) per acre of dry vegetable matter, which would contain 40 per cent. of its weight of carbon as the annual average, we have for the weight of this body in the seven years 17,248 lbs. The organic matter carried to this acre of land in the seven years would, upon the same calculation, comprise 4·928 lbs. of carbon.

These on a recapitulation give for the

| | | |
|---|---|---|
| 1st seven years | Carbon in the soil at the commencement | 34,378 lbs. |
| | Added in the shape of manure | 4,928 |
| | | 39,306 |
| | Carried off in dry vegetable matter | 17,248 |
| | Left at the expiration of the first term | 22,058 |
| 2nd seven years. | Added as manure | 4,928 |
| | | 26,986 |
| | Carried off in dry vegetable matter | 17,248 |
| | Left at the expiration of the 2nd term | 9,738 |
| 3rd seven years. | Added as manure | 4,928 |
| | | 14,666 |
| | Carried off in dry vegetable matter | 17,248 |
| | Deficiency at the expiration of the 3rd term | 2,582 lbs. |

of carbon. Equivalent to 6,455 lbs. of dry vegetable matter, the produce of more than one year.

The reverse of this is so well known to be the case by every one acquainted with agricultural operations, that he hesitates not to say, there must be some other source from whence the plants which grew upon this description of land derive a considerable portion of their carbonaceous matter; for in this case the vegetable matter carried from the land in the three terms, contained 2,582 lbs. of carbon more than was included in the land, and in the organic matter with which it was supplied.

---

* That the subject may not be encumbered with too many calculations upon matters which do not sensibly affect the principles inquired into, I have purposely avoided all notice of that organic matter which is carried into the under strata of the soil by water, &c., and all that which is drawn from it by the long roots of the plants.

This land, if it had retained its original quantity of carbon during the twenty-one years, must have drawn from other sources 36,960 lbs. of carbon, being an average for each year of 1,760 lbs. in the production of plants containing 2,464 lbs. of carbon; and if we calculate for an average produce of three tons per annum, the quantity of carbon derived from other sources must have been 1,920 lbs.

## CARBONIC ACID ONE SOURCE OF CARBON.

One source from whence plants may draw a part of their carbon is the atmosphere, where it exists in combination with oxygen forming carbonic acid gas, after the rate of carbon 6 to 6·12 parts, oxygen 16 parts by weight. The quantity of this gas in the atmosphere is from $\frac{1}{200}$ to $\frac{1}{1000}$ of its volume, varying with the distance from large towns, or places where much of it is given off, from the various sources of combustion, respiration, decay of organic matter, &c.

Dr. Priestley appears to have been the first discoverer of the influence of carbonic acid gas in promoting the growth of plants. He found that when plants performed their healthy functions in an atmosphere which had been rendered unwholesome by respiration of animals, combustion, or putrefaction, the air afterwards became fit for the support of animal life, and that during this renovation the plants grew luxuriantly. In the prosecution of this enquiry he found that these very important changes were dependent upon the operation of the living plants. In *Dr. Priestley's Observations on Air infected with Animal Respiration*, he says, (page 89,) "The air on which I made the experiment was rendered exceedingly noxious by mice dying in it on the 20th of June. Into a jar nearly filled with one part of this air, I put a sprig of mint, while I kept another part in a phial, in the same exposure; and on the 27th of the same month, and not before, I made a trial of them by introducing a mouse into a glass vessel, containing 2½ ounce measures filled with each kind of air; and I noted the following facts:—

"When the vessel was filled with the air in which the mint had grown, a very large mouse lived five minutes in it before it began to show any uneasiness. I then took it out, and found it to be as strong and vigorous as when it was first put in; whereas in that air which had been kept in the phial only, without a plant growing in it, a younger mouse continued not longer than two or three seconds, and was taken out quite dead. It never breathed after, and was immediately motionless. After half an hour, in which time the larger mouse (which I had kept alive, that the experiment might be made with the very same animal, and which would have been sufficiently recruited, supposing it to have received any injury by the former experiment) was put into the same vessel of air; but though it was withdrawn again, after being in hardly one second, it was recovered with difficulty, not being able to stir from the place for near a minute. After two days, I put the same mouse into an equal quantity of common air, and observed that it continued seven minutes without any sign of uneasiness; and being very uneasy after three minutes longer, I took it out. Upon the whole, I concluded that the restored air wanted about one-fourth of being as wholesome as common air; the same thing also appeared when I applied the test of nitrous air."

And after detailing many experiments shewing that the atmosphere is renovated by the growth of plants, he draws the following conclusions:—"These proofs of a partial restoration of air by plants in a state of vegetation, though in a confined and unnatural situation, cannot but render it highly probable that the injury which is continually done to the atmosphere by the respiration of such a number of animals, and the putrefaction of such masses of both vegetable and animal matter, is, in part at least, repaired by the vegetable creation. And notwithstanding the prodigious mass of air that is corrupted daily by the above-mentioned causes, yet if we consider the immense profusion of vegetables upon the face of the earth growing in places suited to their nature, and consequently at full liberty to exert all their powers, both inhaling and exhaling, it can hardly be thought but that it may be a sufficient counterbalance to it, and that the remedy is adequate to the evil."* In the prosecution of this inquiry he found that the power of plants for renovating the atmosphere was greatest when kept under the influence of the sun's rays.

This subject, since the days of Priestley, has been investigated by several vegetable physiologists. It seems now to be an opinion almost universal, that plants derive a part of their carbon from the carbonic acid gas which has been furnished to the atmosphere from the various sources of combustion, respiration, fermentation, animal and vegetable decay, &c.; that this carbonic acid is decomposed by the plants, its carbon is assimilated under the influence of the sun's rays, and its oxygen given off to the surrounding atmosphere.

---

* Priestley on Air, p. 93. 1774.

Professor Liebig, in a work recently published,* informs us that carbonic acid is the source from whence plants derive all their carbon. In support of this proposition he instances the sparing solubility of *humus* and *humic acid* in water, which are regarded by some vegetable physiologists as the food of plants, and argues that these bodies being so sparingly soluble, cannot be conveyed to the roots of plants in sufficient quantities to furnish them with the carbon they require during their growth. Hence he deduces that "humus in the form in which it exists in the soil does not yield the smallest nourishment to plants; the carbon must therefore be drawn from some other source;" and since animal and vegetable matter during its decay gives off carbonic acid gas, which is imparted to the atmosphere, and plants have the power of decomposing this carbonic acid and appropriating the carbon to their own purposes, he concludes "that the carbon of plants must be derived exclusively from the atmosphere."*

---

* "Organic Chemistry in its application to Agriculture and Physiology," page 19.

In a work by Professor Johnston, ("Lectures on Agricultural Chemistry and Geology," Part 1st.) recently published, the principle of plants deriving much of their carbon from the atmosphere is advocated.

From three lectures on Agriculture delivered by Dr. Daubeny, Professor of Chemistry at Oxford, it appears he holds the same views. He informs us that we are indebted to Liebig for explaining

We shall inquire into the correctness of this proposition,—in the first place, with the aid of the results obtained by the ordinary operations of agriculture, and afterwards with that of chemical experiment.

If plants derive *all their carbon from carbonic acid*, they may draw it from the three following sources: viz. from the atmosphere which surrounds them; from that atmosphere which fills the interstices of the soil in which they grow; and from the water which is in contact with the earth.

Assuming that the same kind of plants when placed under equal circumstances as respects climate, exposure, &c. have equal powers of abstracting carbon from the above sources, such plants growing near to each other upon good and inferior lands, will be placed under equally favourable circumstances so far as the carbonic acid in the atmosphere, and in the water is concerned. The difference in their growth upon the two kinds of lands, will be due therefore to the difference in the quantity of carbonic acid the plants are brought in contact with, which may be formed by the decomposition of the organic matter contained in the two kinds of land. Hence the difference in the weight of organic matter susceptible of forming carbonic acid in soils, will be the true measure of the relative quality of land, and of the weight of plants that will be produced.

If this be a correct proposition as respects plants

more clearly than has hitherto been done how it happens that the atmosphere is the source from whence plants derive their carbon, and says, "We seem therefore to be justified in attributing the carbon which plants contain exclusively to the decomposition of carbonic acid, which, before the leaves are developed, is introduced together with the sap by the roots, but afterwards is obtained directly from the air itself."—*Lectures on Agriculture,* 1841 and their food, on our ascertaining by *ultimate analysis*, the weight of carbon in the organic matter contained in any soil; and knowing how much of this body is contained in the manure with which it is supplied, we should find no difficulty in determining the comparative productiveness of any given samples of soils.

If, for example, a given measure of good land contained 10,000 parts of carbon in the organic matter, and the same measure of inferior land contained only 5000; by adding to the latter 5000 lbs. of carbon in the shape of manure, we should have the inferior land in as good condition for producing plants as the good land, and the two soils, after being once placed under equal circumstances, would, if this principle be a correct one, remain the same for any length of time, provided the two portions of land produced the same kind and weight of plants every year.

## OF FERTILE LAND.

For the illustration of this subject I have selected experiments made upon soils of good and likewise of inferior quality, obtained from Essex, Middlesex and Surrey as the southern district; and from soils from different parts of the same farm in Cumberland for the northern district.

The first experiment to be described was made upon a very productive soil from Essex. This land is not manured more than once in fifteen or twenty years, and by occasionally fallowing, is kept in its very fertile condition. During the last eleven years it has produced five very abundant wheat crops, two of potatoes, one of beans, and two of pease, with one year's clean fallow.

The weight of dry vegetable matter carried from the soil was at least equal to thirty-three tons. No organic matter was carried to this land during this period, and it is at present considered to be in as good condition; and, in every respect as productive as it was eleven years ago.

An average sample of this soil, in that state of moisture which is well fitted for the growth of plants, was constituted of*

| | | | | |
|---|---|---|---|---|
| Organic matter | Carbon | 2·48 | | |
| | Nitrogen | ·38 | | |
| | Hydro. and Oxy. | 2·74 | 5·6 | |
| Water | | | 34·2 | |
| Carbonate of lime | | | 1·2 | |
| Oxide of iron | | | 0·6 | |
| Fine sand | | | 16·4 | |
| Very adhesive clay | | | 42·0 | 100 |

An acre of this land, six inches deep, and lying upon a subsoil from $\frac{1}{5}$ to $\frac{1}{6}$ heavier than the same bulk of water, would weigh about 1,599,000 lbs., containing 89,544 lbs. of organic matter, comprising 39,655 lbs. of carbon and 6076 of nitrogen.

The thirty-three tons (73,920 lbs.) of dry vegetable matter carried from an acre of this land in eleven years would contain 29,568 lbs. of carbon.

According to this statement, which we have no reason to doubt, this land is now as rich in organic matter, and is in every respect as capable of producing plants as it was eleven years ago; we may suppose that it now contains as much carbon as it did at that period. An equivalent in weight to the carbon which entered into the constitution of the plants carried from this land must therefore have, during these eleven years, proceeded from other sources. Upon the supposition that there are no other sources from whence plants derive their carbon than the carbon in the soil, in the water, and in the atmosphere; plants growing upon this description of land would either derive $\frac{10}{11}$ of their carbon from the carbonic acid in the atmosphere during their growth, or this kind of earth must first take up this gas and afterwards impart it to the plants as they may require carbon. In this instance the quantity of carbon so appropriated every year is 2688 lbs., as much as is comprised in 9856 lbs. of carbonic acid.

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* It was my intention when this and the other soils hereafter to be noticed were analyzed, to have submitted their more earthy parts to further examination, but this was prevented by their getting mixed in the interval.

The next experiment was made upon a fertile soil, which is now in as productive a condition as at any period during the last forty-three years. It is situated in the northern part of the county of Cumberland; an average sample was constituted of

| | | | |
|---|---|---|---|
| Organic matter | Carbon . . . | 2·02 | |
| | Nitrogen . . | ·34 | |
| | Hydro. and Oxy. | 2·64 | 5·0 |
| Water when in its productive state . . | | | 36·0 |
| Siliceous sand . . . . . . | | | 35·0 |
| Clay . . . . . . . | | | 24·0—100 |

| | |
|---|---|
| This land during this period has been pastured by horses employed in agriculture | 19 years. |
| Has been under green crop . . | 4 „ |
| Has been under white crop . . . | 20 „ |
| | 43 |

It has been supplied either five or six times with manure, after the rate of four tons per acre.

On making our calculations, as in the last experiment, for six inches depth of soil, an acre weighing 1,599,000 lbs., would contain 32,300 lbs. of carbon and 5,337 of nitrogen. To this must be added, for organic matter carried to this land during the twenty-four years it was under tillage, at most twenty-four tons (53,760 lbs.), containing 21,504 lbs. of carbon; and if we add the same weight for that left in the field by the cattle during the period it was under pasture, we have the weight of organic matter in an acre of this land, and what was carried to and left upon it during the forty-three years, as under:—

| | Organic matter. | Carbon. |
|---|---|---|
| Original quantitiy in the soil | 80,276 | 32,107 lbs. |
| Carried to the land. . . | 53,760 | 21,504 „ |
| Left by the horses . . | 53,760 | 21,504 „ |
| | 187,796 | 75,115 |

This land has always been very productive. If, therefore, we make our calculation for the quantity of dry vegetable matter carried off every year, after the average rate of 2·75 tons (6,170 lbs., a quantity rather under than over the real produce) containing carbon after the rate of forty per cent., we find there has been carried off during the last forty-three years—

| | Vegetable matter. | Carbon. |
|---|---|---|
| From an acre of this land . | 265,310 | 106,124 lbs. |
| Remaining on the field . | 80,276 | 32,107 „ |
| | 345,586 | 138,231 „ |

giving an average for the forty-three years, 1,468 lbs.

From this we conclude, that if the proposition under consideration be correct, in order to bring about this annual produce, the plants upon every acre must have abstracted from the carbonic acid in the atmosphere, 1,468 lbs. of carbon in the production of 2¾ tons per acre, equal to 1,599 lbs. in the production of three tons of dry plants.

## OF INFERIOR LAND.

A large portion of the arable land in Great Britain owes much of its fertility to a judicious course of husbandry. By this some inferior lands are made to produce almost twice as much as the same description of soil under a less judicious mode of cultivation.

The analyses of these less productive soils, together with their proceeds and the organic matter carried to them, will assist us in forming correct conclusions respecting the sources from whence plants derive their carbon.

The land which forms the first experiment is situated in Surrey. It lies upon a gravelly subsoil, and may be worked at any time when the weather is favourable. By good management under the *four course* system it is considered productive land.

An average sample of this land was composed of

| | | | |
|---|---|---|---|
| Organic matter | Carbon | 1·57 | |
| | Nitrogen | ·12 | |
| | Hydro. and oxy. | 1·81 | 3·5 |
| Water when in its fertile condition | | | 18·5 |
| Loose stones | | | 4·0 |
| Silicious sand | | | 63·0 |
| Ferruginous clay | | | 11·0—100 |

An average produce of the four years is about 2¾ tons (6,160 lbs.) for each year.

In order to keep this land in an equable productive condition, the quantity of dry organic matter which is required to be carried to it as manure, during one course, weighs upon an average, one-sixth less than the dry vegetable matter removed from it.

On making our calculations, as in the former experiments, we find that an acre of this land, six inches deep, weighs 1,599,000 lbs., and contains 55,965 lbs. of organic matter, comprising 25,104 lbs. of carbon, and 1,918 of nitrogen. The vegetable matter carried from this acre would be in the four years 24,640 lbs., comprising 9,856 lbs. of carbon; and the organic matter carried to it, would weigh 19,612 lbs., and comprise about 7,800 lbs. of carbon.

On recapitulation we have

| | Organic matter. | Carbon. |
|---|---|---|
| In the acre of land at this time | 55,965 | 25,104 lbs. |
| Carried from the land . . | 24,640 | 9,856 „ |
| | 80,605 | 34,960 |

Upon the supposition that this land was in a good condition at the commencement of the course, we have

| | Vegetable matter. | Carbon. |
|---|---|---|
| In the acre of land 4 years ago | 55,965 | 25,104 lbs. |
| Carried to it . . . . | 19,612 | 7,800 „ |
| | 75,577 | 32,904 |

These give us, as derived from other sources, in four years, 2,065 lbs. of carbon, being 514 lbs. for the average of each year upon the production of 2¾ tons, and 534 lbs. upon the production of three tons of dry plants.

The next experiment is an analysis of a sample of earth from the last-mentioned farm. The colour of the soil had a light blue tinge. It lay upon a stiff clay subsoil, containing considerable quantities of oxide of iron. It had been rendered more productive by *under-draining*, and was constituted of

| | | | |
|---|---|---|---|
| Organic matter | Carbon . . | 2·18 | |
| | Nitrogen . | 0·10 | |
| | Hy. and Oxy. | 2·52 | —04·8 |
| Water when in its vegetating state . . | | | 28·2 |
| Silicious sand . . . . . | | | 51·0 |
| Clay with traces of oxide of iron . . | | | 16·0—100 |

Under the *four-course* system of management the produce of dry vegetable matter carried from an acre, was about twelve tons in the four years. The land being cultivated in this manner was considered at the end of each course, of equable condition. An acre of the soil about six inches deep, would contain 76,752 lbs. of organic matter, including 34,858 lbs. of carbon and 1,599 of nitrogen.

On calculating for an annual average produce of three tons, the weight of dry vegetable matter yielded by an acre in the four years, would be 26,880 lbs., containing 10,752 lbs. of carbon. The dry organic matter with which it was enriched would be 22,400 lbs., and include about 8,960 lbs. of carbon.

The soil at the commencement and at the conclusion of a course of crops being the same as regards organic matter, the weight of carbon carried to it being 8,960 lbs., the quantity obtained from other sources is 1,792 lbs. in the four years, equal to 448 lbs. per annum for three tons produce.

## OF BAD LAND.

The soils chosen to illustrate this subject are naturally very unproductive, and unless kept under a system of rich manuring, will yield crops scarcely worth getting in. The first is a soil from Surrey, which lies upon a gravelly subsoil, and upon analysis, was found to be constituted of—

| | | | |
|---|---|---|---|
| Organic matter | Carbon | 1·76 | |
| | Nitrogen | ·07 | |
| | Hydro. and Oxy. | 2·07 | |
| | | | 3·9 |
| Water, about | | | 20·1 |
| Coarse gravel | | | 25·0 |
| Light-coloured sand | | | 51·0 |
| | | | 100 |

An acre of this land, five inches deep, would weigh 1,322,500 lbs., and would contain 515,775, comprising 23,276 lbs. of carbon.

By the addition of from ¼ to ½ dry organic matter as manure, more than it yields of dry vegetables in the four years course of husbandry. The crops which it produces average about two tons per acre per annum, making the weight of produce in eight years 16 tons (35,840 lbs.)

By calculating for the weight of dry organic matter comprising 40 per cent. of its weight of carbon, carried to an acre of this land in eight years, at 22 tons, we have 49,280 lbs., containing 19,712 lbs. of carbon derived from this source.

The land, by this mode of cultivation, being kept in an equable condition, the quantity of organic matter would be the same at the end of each course. The following may therefore be considered the condition as respects the carbon:—

| | Carbon. |
|---|---|
| In the organic matter carried to the land in eight years | 19,712 lbs. |
| In the vegetable matter carried from the land in eight years | 14,336 „ |
| Loss of carbon in eight years | 5,376 „ |

equivalent to an annual loss of 672 lbs. upon a produce of two tons per acre, and 1,008 lbs. on the produce of three tons.

The next example was from the farm in Cumberland already mentioned. This soil was naturally very unproductive. It lay very lightly upon a hard gravelly subsoil, wherein tiles had been laid for drainage. It was constituted of—

| | | | |
|---|---|---|---|
| Organic matter | Carbon | 2·42 | |
| | Nitrogen | ·18 | |
| | Hydro. and oxy. | 2·80 | |
| | | | 5·3 |
| Water | | | 15·7 |
| Light-coloured stones | | | 28·0 |
| Silicious sand | | | 44·0 |
| Aluminous earth | | | 7·0 |
| | | | 100 |

The crops, for the last thirty years or upwards, have been, with little variation, after the following order:—one turnips, one potatoes, one wheat, one barley, one hay, two pasture, and one oats, being richly manured for the first mentioned three crops.

The dry organic matter carried to this land contained from 34 to 40 per cent. of its weight of carbon, and was more than twice the weight of the dry vegetable matter carried from it, which was upon an average about two tons (4,480 lbs.) per acre per annum. These give for the organic matter carried to this land in twelve years 107,520 lbs., containing 43,000 lbs. of carbon; and for the weight of the dry plants 53,760 lbs., containing 21,504 lbs. of carbon. An acre of this soil, five inches deep, would weigh about 1,322,500 lbs., and contain 70,092 lbs. of organic matter, containing 32,004 lbs. of carbon and 238 lbs. of nitrogen. Supposing this land to remain stationary as to the quantity of organic matter contained in it, at the end of every twelve years we have the following results:—

| | Organic Matter. | Carbon. |
|---|---|---|
| Originally in the soil | 70,092 | 32,004 |
| Carried to it in 12 years | 107,520 | 43,000 |
| | 177,612 | 75,004 |
| At present in the soil | 70,092 | 32,004 |
| Carried from it in 12 years | 53,760 | 21,504 |
| | 123,852 | 53,508 |

These give an annual loss of 1,722 lbs. of carbon in the production of two tons of plants.

## OF MEADOW LAND.

Meadow lands afford good illustrations of the subject under consideration. The sample which forms the subject of the following experiment is an average specimen of meadow land, which is seldom enriched by manure. It was taken from a field at Greenford, in Middlesex, which is occasionally inundated. On the water abating, there is deposited a considerable portion of clayey mud, which contains little or no organic matter. I found a fair sample of this soil, six inches deep, to be constituted of—

| | | | |
|---|---|---|---|
| Organic matter, including several roots of grass | Carbon | 3·48 | |
| | Nitrogen | ·26 | |
| | Hydro. & Oxy. | 3·86 | |
| | | | 7·6 |
| Water, when in its vegetating state | | | 39·4 |
| Clay | | | 46· |
| Silicious sand | | | 7·0 |
| | | | 100 |

An acre of this land, six inches deep, weighs 1,599,000 lbs., and contains 121,524 lbs. of organic matter, including 55,645 lbs. of carbon, 4,157 of nitrogen. This land is mown every year between the middle and the latter end of June; the average weight of dry hay, which contains 40 per cent. of carbon, is about a ton and a half per acre. The *aftermath* and autumnal grass are generally eaten off by cattle or sheep. The annual proceeds of vegetable matter carried from an acre of this land may be estimated at 2¼ tons, (5,040 lbs.) containing 2,016 pounds of carbon, which has principally been derived from foreign sources.

From these experiments it is apparent that the carbon in the organic matter contained in or laid upon some soils, falls very short of the quantity of carbon contained in the plants produced by them; and that in other soils situated in the same climate, the quantity of carbon contained in the plants produced falls very far short of the carbon contained in the organic matter belonging to, or laid upon the land; as will appear in a more compact form from the following Table, (page 24,) to which is added columns of proportion, 100 being the maximum weight of carbon.

On referring to this table, a great difference will be found in the weight of the carbon to the acre belonging to the different soils experimented upon. But the inferior soils may generally be raised, by the addition of manure to the same condition with respect to carbon as the fertile. They will then be all in a similar condition for producing carbonic acid, and being situated in the same climate, plants of the same kind growing therein will have equal facilities for taking up carbon.

| DESCRIPTION OF SOIL. | Page. | Pounds of Carbon | | Pounds of Carbon | | Pounds of Carbon carried to an Acre annually. | Excess of Carbon carried off over that carried to the Land annually. | | Excess of Carbon carried to the Land over that carried off it per Acre annually. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | In an Acre of the Land. | Per Cent. | Carried off an Acre annually. | Per Cent. | | Lbs. | Per Cent. | Lbs. | Per Cent. |
| Good soil in Surrey ........ | 6 | 34,378 | *86 | 2,468 | 92 | 704 | 1,764 | 71 | .... | .... |
| Good soil in Essex.......... | 13 | 39,655 | *100 | 2,688 | 100 | none | 2,688 | 100 | .... | .... |
| Good Soil in Cumberland.... | 15 | 32,300 | *81 | 2,468 | 92 | 1,000 | 1,468 | 59 | .... | .... |
| Inferior soil in Surrey ...... | 17 | 25,104 | *62 | 2,468 | 92 | 2,056 | 514 | 18 | .... | .... |
| Inferior soil in Surrey ...... | 18 | 34,858 | *87 | 2,688 | 100 | 2,240 | 448 | 17 | .... | .... |
| Bad soil in Surrey .......... | 19 | 23,276<br>27,931 | †58<br>*70 | 1,792 | 67 | 2,464 | .... | .... | 672 | 37—56 |
| Bad soil in Cumberland .... | 21 | 32,004<br>38,405 | †80<br>*96 | 1,792 | 67 | 3,584 | .... | .... | 1,792 | 100—150 |
| Average productive clayey soil (meadow) in Middlesex.. | 22 | 55,645 | 144 | 2,016 | 75 | little or none | 2,016 | 75 | .... | .... |

* 6 inches deep. † 5 inches deep.

If, therefore, the proposition be correct, that plants derive all their carbon from carbonic acid, six of these soils may all remain for any length of time equally productive. This, however, is contrary to experience, for although by the addition of organic matter different fields in the same farm may be equalized as to the quantity of carbon they contain, instead of remaining so for many years, they become at the expiration of the first, second, or third year, very dissimilar in their productiveness.

If, for example, a farmer in the first year of a course of husbandry, takes good land, inferior land, and bad land, an acre of each, and charges them with the same quantity of carbon, making them to contain 39,655 lbs. of carbon each. The good land will yield 3 tons of dry plants annually, the inferior land 2¾, and the bad land 2 tons only, for each of the three first years. On preparing for the fourth year's produce, he finds the good land as rich in carbon, and in nearly as fertile a condition as at the commencement of the course; while the inferior land, and in a still greater degree the bad land, have undergone such a loss of carbon as to render a fresh supply of organic matter necessary. Hence we may infer, 1st, That the good land has either lost none of its original carbon, or that it has the power of renovating itself, reproducing carbon in a manner unknown to us;—2nd, That the inferior land requiring supplies of organic matter in order to keep it in its productive condition, must lose a portion of its carbon, and that its power of renovating itself must be less than that of the good land;—and 3rdly, That the bad land requiring to be replenished with a still greater quantity of carbon, must, in the process of vegetation, either destroy its carbon altogether, or render it unfit for being assimilated by plants.

These inferences will be more clearly illustrated by representing—

| | | | Organic matter | Produce. |
|---|---|---|---|---|
| Good land | . . . . | | 100 | 100 |
| Inferior land | organic matter | 95 | | |
| | carried to it | 5 | 100 | 92 |
| Bad land | organic matter | 90 | | |
| | carried to it | 20 | 110 | 67 |

Other inferences may be drawn. The three qualities of soil with reference to their power of producing or destroying their carbon, may be represented as under:—

| | | | |
|---|---|---|---|
| Good land | carbon derived from the soil and the atmosphere | 92 | |
| | carbon made by plants | 8 | 100 |
| Inferior land | carbon derived from the soil and the atmosphere . . . | | 92 |
| Bad land . | Ditto ditto | 92 | |
| | carbon lost by a process unknown . . . . | 25 | 67 |

But, that view of this subject which is most in accordance with the phenomena that accompany the decomposition of organic matter, and the growth of plants upon these soils, is the following,—

| | | |
|---|---|---|
| Carbon made by the plants growing in the good soil . . . | 50 | |
| Carbon derived from the atmosphere | 20 | |
| Do. from organic matter in the soil | 30 | |
| | | 100 produce. |
| Carbon made by the plants growing in the inferior soil . . | 37 | |
| Carbon derived from the atmosphere | 20 | |
| Do. from organic matter in the soil | 35 | |
| | | 100 „ |

| | | |
|---|---|---|
| Carbon made by the plants growing in the bad soil . . . | 5 | |
| Carbon derived from the atmosphere | 20 | |
| Do. from organic matter in the soil | 42 | |
| | | — 100 produce. |

Having explained the six first columns in the table, we now come to the seventh column,—the excess of carbon carried off, over that carried to an acre of land.

In order to illustrate this subject let the following, extracted from the above table, represent the proportions of carbon in the organic matter contained in the respective soils therein mentioned, and also the excess of carbon carried off, over that carried to the land.

| | Carbon in organic matter contained in the soil. | Excess of carbon carried off, over that carried to the land. |
|---|---|---|
| Good soil from Essex | 100 per cent. | 100 per cent. |
| " " Surrey | 86 " | 71 " |
| Inferior do. Surrey | 62 " | 18 " |
| " " " | 87 " | 17 " |
| Meadow, Middlesex . | 144 " | 75 " |

It appears that the excess of carbon in the best land is in the proportion of 100 per cent., while in the produce of the inferior land it is only in the proportion of 71, 18, and 17 per cent.; the proportions decreasing with the quality of the land; but all these soils are similarly situated as to climate, and other external circumstances, and the plants growing therein have equal facilities for extracting carbon from the atmosphere, they may therefore be supposed to extract equal quantities. If, therefore, the produce of the best land extract a proportion of 100 per cent. from the atmosphere, that of each of the other must do the same. Now, the quantity of carbon extracted from the atmosphere by the produce of each of these soils being the same, yet the total quantity of carbon contained in the produce of each being very different, that produce in which the total quantity of carbon is least (i. e. the produce of the worst land), must extract the least carbon from the organic matter contained in the soil; therefore that organic matter will be less exhausted than that in the better soils, and will need less renewing. In other words, while the best land remained stationary, inferior lands instead of being deteriorated by the process of vegetation, and requiring fresh supplies of organic matter, would be gradually enriched, and would in each year gain a quantity of carbon, increasing in proportion to their original sterility, which is contrary to all experience.

This argument applies still more forcibly in those cases in which there is a deficiency, instead of an excess of carbon, as will appear from the following table, exhibiting Theory and Experience.

| | THEORY. | | EXPERIENCE. | |
|---|---|---|---|---|
| | Carbon per cent. | Tons per acre annually. | Carbon per cent. | Tons per acre annually. |
| Good soil in Surrey ...... | 129 | 3·87 | 92 | 2·75 |
| Ditto in Essex .......... | 100 | 3·0 | 100 | 3·0 |
| Ditto in Cumberland...... | 141 | 4·23 | 92 | 2·75 |
| Light gravelly soil in Surrey | 180 | 5·40 | 92 | 2·75 |
| Light clayey soil in Surrey | 183 | 5·49 | 100 | 3·0 |
| Bad ditto ditto .. | 157 | 4·71 | 67 | 2·0 |
| Bad in Cumberland ...... | 228 | 6·84 | 67 | |
| Meadow land in Middlesex | .. | .. | 75.. | 2·25 |

And further, in whatever manner we make experiments upon the growth of plants, so as to obtain the gaseous products in a situation suitable for testing, we find that plants which perform their healthy functions, and grow the quickest, contain the most carbon, and give off the greatest proportion of carbonic acid to the surrounding atmosphere; this being the case in the ordinary course of vegetation, a field which produces three tons of dry vegetable matter per acre, will necessarily give off more carbonic acid than a field which only produces two tons. Now, we have experimental evidence that the weight of carbon which is contained in the carbonic acid given off by plants, exceeds that which is contained in the plants produced, and the carbon which is given off, as carbonic acid, in a greater proportion from those plants which increase the most in carbon, than from those plants which increase less in this body.

It would therefore appear that instead of plants which grew upon unproductive land, giving off carbonic acid, the carbon of which might be taken up by plants growing upon the very productive land in a neighbouring field, the reverse takes place. This is better illustrated, by the two following experiments upon seedling turnips.

| | Carbon in the plants. | Carbon in the carb. acid given off. |
|---|---|---|
| From the experiment which yielded . . . . | 100 parts | 110 parts. |
| From ditto ditto . | 67 „ | 70 „ |

The plants which vegetated in the more fertile earth, yielded 100 parts of carbon; and the carbonic acid imparted to the atmosphere contained 110 parts of carbon. The same kind of plants, which grew under equal circumstances in less fertile earth, yielded 67 parts of carbon; and the carbonic acid imparted to the atmosphere comprised only 70 parts of carbon.

Hence it may be inferred, that the carbon in the carbonic acid in the atmosphere forms but a small portion of that which enters into the constitution of the plants; and it may be added that there is probably no feature in practical agriculture, which, when fully examined, will warrant any other conclusion.

### EVIDENCE ADDUCED IN SUPPORT OF THE CARBON IN PLANTS BEING DERIVED FROM THE ATMOSPHERE.

The evidence in support of the theory, that plants derive all their carbon from the carbonic acid in the atmosphere, is rather of a deductive than an inductive character. It has been ascertained by experiment, that seeds, roots, and plants, live, and send forth leaves, flowers, and fruit, without being in contact with earth or organic matter, upon being supplied with water, and kept in an atmosphere which always contains carbonic acid; yet these furnish no conclusive evidence that the carbon contained in their leaves, flowers, &c., has been derived from the atmosphere.

The first experimental fact in support of this theory is found in an account (abridged) of a suspended plant of *Ficus Australis*, which grew for eight months without earth in a stove, under the management of Mr. W. Macnab, superintendent of the Botanic Garden at Edinburgh.

When Mr. Macnab came to superintend that garden, in 1810, this plant was in a less thriving condition than he had been accustomed to see it. In 1811 he placed it in a hotter situation, where it began to grow vigorously. After it had been in this situation for some time, he says, "I observed a root set out from the stem, about a foot above the earth of the pot in which it was placed. As soon as the root had extended downwards about eight inches, I placed a pot of earth under it, and it soon took hold of the earth and filled the pot with fibres, like those belonging to the original root of the plant. In this state I allowed matters to remain for about a year, when the root from the stem had increased to nearly half an inch in diameter. In the spring of 1814, I cut off the exposed root close to the stem from whence it had issued, principally with a view of observing whether it would put out leaves and branches, and thus be converted into the stem of a new plant; but, although the whole remained fresh for a considerable time, no buds or leaves were ever produced.

"The original plant soon put out more roots from the stem, which is about a foot in height, before any branches set out; on one of the branches, above two feet from the junction with the stem, a root was also put out. As soon as this last had grown about a foot long, I placed a pot under it, in the same way as I had formerly done. As soon as I found the pot filled with roots, I determined to try whether this third pot, if plentifully supplied with water, would support the whole plant. In August, 1816, I left off watering the largest pot, and supplied the other (the third) very freely with water. I kept it in this state for about eight months, till the earth in the large pot was so completely dry that I was satisfied the plant would receive no nourishment from it.

"The shrub continued quite as healthy and vigorous as when supplied with water at the original root. In the spring of 1817, I took off the largest pot in which the original roots were, and exposed the roots to the full rays of the sun, by gradually shaking off the dry earth from among them. This had no ill effect on the plant, as it still remained perfectly healthy. It, however, had the effect of making roots to be put out out freely all over the plant, much more so than had hitherto been the case.

" In the latter end of the summer of 1817 I placed a root in a fourth pot, which was put out from a branch about three feet from the junction with the stem, and on the opposite side of the plant from that which had supported it for some time past. As soon as I found this pot filled with fibres, I supplied it freely with water, and kept the third pot dry, as I had done before with the original root. I found the plant still continue equally vigorous as before. In the spring of 1818 I took away the third pot, which I had for some time kept dry, and exposed the roots gradually, as I had formerly done with those in the original pot. I may observe that in both cases the plant began to push out young shoots and leaves, rather earlier on the branches on the *opposite* side of the tree to that on which the pot was attached; the difference, however, was very inconsiderable.

"This fourth pot, which now alone supported the plant, was four feet from the lower end of the stem, and very near to the extremity of the branch; the original roots and the second set of roots both hanging loose in the air. The plant, however, remained in this state for nearly a year, in perfect health. In May, 1819, I took a very small pot, about two inches in diameter, and filled it with earth, as I had done the others, and set it on the surface of the earth in the fourth pot, which now supported the plant. Into this small pot I now introduced a root which came from the same branch, a little below the one which was in the larger pot. As soon as the small pot was filled with roots, I supplied it freely with water, and gave the larger pot none but what might happen to run through the smaller one. After remaining in this state for nearly two months, I cut the branch off between the two pots; I still supplied the small pot only with water, but occasionally, at this time, threw a little water over the whole plant. It continued to look as well as it had done before. In July, 1819, I examined this small pot, and found it completely filled with roots, very little earth remaining in the pot; and I determined to try whether it would live wholly *without earth.* I accordingly took the small pot off, and gradually worked off what earth remained among the roots. I at this time, however, threw plenty of water over the leaves, generally twice in the day; this was done about the latter end of July, when the weather was very warm, but it seemed to have no bad effects on the *ficus.* The plant, I may remark, could not have been in a warmer part of the stove, being close to the roof, where the stove is always the hottest, and quite exposed to the full rays of the sun. The branch which had been cut off was kept growing in a pot of earth, in the usual way, close beside the original plant in the stove; and both appeared on an equality as to health and vigour. What may appear rather remarkable is, that though this ficus is a plant by no means free in producing fruit in the usual way of cultivating it, this specimen, quite suspended without a particle of earth, was loaded with figs during the months of September, October, and part of November. Two fruit were produced at the axilla of almost every leaf; and these were quite as large as I had ever seen on the plant in the hothouses of Kew Gardens.

"The original plant now looks nearly as well as the separated one, which is growing close beside it. It is even beginning to grow or extend, although it has now been suspended for eight months without a particle of earth. Roots have been put out very freely all over the stem and branches during that time. The plant now measures 7½ feet between the extremity of the root and the top of the branches; and the stem at the thickest part is 5½ inches in circumference." (18th February, 1820.)*

This experiment is stated in the Appendix to Liebig's Agricultural Chemistry, in support of his theory upon the sources of the carbon in plants; and on it he observes, "Fresh proof of the accuracy of our theory respecting the origin of carbon would be superfluous and useless."†

We have no proof, in this experiment, that the weight of carbon in the leaves, fruit, root, and stems of this plant, was greater at the expiration of the eight months, than it was when the earth was entirely removed from the root. That it took carbon from the carbonic acid in the atmosphere will be admitted as a consequence necessarily following the developement of the leaves, fruit, &c.; and that the leaves, during the absence of the sun's rays, gave off carbonic acid, will also be generally allowed; but that the roots, stems, leaves, and fruit of this plant abstracted, more carbon from the atmosphere, than was imparted to it by the plant, by as much as was contained in the leaves and fruit, is not evidenced by this experiment.

Had we been furnished with the weight of the plant, when the earth was entirely removed from its roots, in July; and also its weight, together with that of the leaves and fruit in their natural and dry state, in February; and if this weight, at the latter period, exceeded that in the former, we might have concluded that this increased weight of carbon, must have proceeded, either from the carbonic acid in the atmosphere, or have been made by the plant.

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* The Edinburgh Philosophical Journal, Vol. iii. page 79.

† Page 61.

Supposing the whole plant in July weighed 100 lbs., and contained 30 lbs. of carbon, there is no evidence to shew that it weighed more than 100 lbs., or contained more than 30 lbs. of carbon in February. It is stated that the original plant, at the expiration of the term, "looked nearly as well" as the separated one, which was growing in a pot containing earth, close by its side; but as we have no further account of the comparative progress of the two plants, we are warranted in coming to no other conclusion, than that, the *Ficus Australis* is a plant, capable of luxuriant growth under the sole influence of temperature and moisture; and that it is very little indebted to the earth, in which it grows, for its support. But that plants derive their carbon from the carbonic acid in the atmosphere, is not proved by this experiment, any more than by the growth of bulbous roots in water. This want of proof, however, appears at first sight to be supplied by the experiments of M. de Saussure.

Saussure put several roots of mint into bottles filled with distilled water, and placed them outside a window with a southern aspect. On drying some of these plants, he found that 100 parts in weight contained 40·27 parts of dry vegetable matter, which, upon carbonization, left 10·96 parts of charcoal.

The 100 parts of mint, after growing in the air for two months, weighed when green 216 parts. They were reduced by drying to 62 parts; giving an increase of 21·71 parts of dry vegetable matter. These 62 parts, by carbonization, yielded 15·78 parts of charcoal, being an increase of 4·82 parts of carbon.

He also planted four bean-seeds, weighing 120 grains, in a glass capsule containing hard flint, and watered them with distilled water; after vegetating in the air for three months, the weight of the green plants was 1,642 grains, which, on being dried, were reduced to 202 grains. These had nearly doubled their quantity of dry vegetable matter. On carbonization, the plants gave 51 grains of charcoal. Four beans similar in weight to those experimented upon gave 22¾ grains of charcoal. So that these beans, had more than doubled their quantity of carbon by vegetating in the free air when supplied with distilled water.

The inference which M. de Saussure draws from these is, that these plants had increased their quantity of carbon by the decomposition of carbonic acid, which they had found in the atmosphere; for he learned from other experiments, that plants which grew under receivers filled with pure atmospheric air, never increased their carbon.

Admitting that this method of carbonization furnishes the proportionate quantity of carbon in the plants when first put into distilled water, and after they had vegetated for three months, we have no certain evidence that all this increased quantity of carbon proceeded from the carbonic acid in the atmosphere; for aught we learn to the contrary from these experiments, there might have been as much carbon given off to the surrounding atmosphere in the nights, and during cloudy weather, as was taken up from it during the direct influence of the sun's rays. Therefore until we have sufficient evidence that plants remove more carbonic acid from the atmosphere than they impart to it, any theory based upon the larger proportion being removed, is of too speculative a kind to be deserving of much credit. To draw the conclusion from any proof that we have that plants remove more carbon from the atmosphere than they impart to it, because we do not happen to be acquainted with any other process by which any considerable quantity of carbonic acid is removed from the surrounding air, is assuming *that* to be principle which may in reality be a fallacious proposition.

Besides, there is no evidence to prove that plants may not, by a process, the nature of which we are ignorant, have the property of increasing their quantity of carbon during its vegetation in distilled water, and kept in an atmosphere containing a small proportion of carbon.

In the absence of evidence (which these experiments do not furnish) that this increased weight of carbon was the same as that of the carbon removed from the carbonic acid in the atmosphere, it is somewhat unsafe to draw deductions upon so important a feature in vegetable economy; for it will be shown, that while in some plants there is found an increase of carbon when supplied with water only, in others there is a deficiency, upon the original quantity contained in the seed or plant.

The same objections apply to the following experiments which I made upon this subject. I took sprigs of Michaelmas daisy, star-wort and of chrysanthemums, each weighing 100 grains; some of each I immediately dried, and analyzed with oxide of copper; others I placed, on the 8th of May, in eight-ounce white glass bottles nearly filled with water, containing $\frac{1}{3500}$ parts of earthy and $\frac{4}{7000}$ of organic matter.

The latter commenced growing from the first; very few new leaves were put out, but long roots from each sprig shot forth during the summer. In the autumn the Michaelmas daises budded, and in December the chrysanthemums. When the flowers were fully expanded, each sprig was dried; and those which had increased most in weight were powdered, and the dried powder, after being exposed to the atmosphere for 24 hours, was subjected to analysis. These in their dry state, when compared with the weight of the young shoots in May, gave—

| | Dry Sprigs in May. | The whole dry Plants after flowering. | Increase. |
|---|---|---|---|
| Michaelmas daisy, | 15·6 | 34·5 | 18·9 |
| Chrysanthemum.. | 16·2 | 38·6 | 22·4 |

They gave by analyses—

| | | Carbon. | Hyd. | Oxyg. | Nitr. | Ashes | Total. |
|---|---|---|---|---|---|---|---|
| Michaelmas Daisy | Young shoots, | 5·77 | 1·03 | 7·40 | ·78 | ·62 | 15·6 |
| | After flowering, | 13·11 | 2·13 | 17·06 | 1·12 | 1·08 | 34·5 |
| | Increase ...... | 7·34 | 1·1 | 9·66 | ·34 | ·46 | 18·9 |
| Chrysanthemum | Young shoots, | 6·31 | ·94 | 7·47 | ·64 | ·84 | 16·2 |
| | After flowering, | 15·22 | 2·32 | 18·67 | 1·16 | 1·23 | 38·6 |
| | Increase ...... | 8·91 | 1 ·38 | 11·20 | ·52 | ·39 | 22·4 |

The green matter, which generally forms at the bottom and sides of the bottles in which experiments of this kind are made, contained more carbon than would be imparted by the water to the plants during their growth; the water likewise held a considerable portion of organic matter in solution, which was obtained by careful evaporation, but was not analyzed.

The water in which these plants vegetated always contained carbonic acid in greater abundance than that with which they were supplied, and especially when they were sending forth flowers. The water therefore, rather took carbon from the plants than added any to them.

Professor Liebig adduces also the experiments made in the Botanic Gardens at Munich by Edward Lucas, in support of the view, that carbonic acid in the atmosphere is the source from whence plants derived their carbon. Mr. Lucas substituted charcoal in fine powder for tan, in which he planted a great number of tropical plants. The plants vegetated quickly, and wore a healthy appearance, and surpassed those cultivated in the usual manner in the thickness of their stems, colour of their leaves, and the beauty of their blossoms. The reader will find more extensive observations in the *Allgemeine deutsche Gartenzeitung* of Otto and Dietrich, in Berlin. Lucas says:—

"The action of charcoal consists primarily in its preserving the parts of the plants with which it is in contact, whether they be roots, branches, leaves, or pieces of leaves, unchanged in their vital power for a long space of time, so that the plant obtains time to develop the organs which are necessary for its further support and propagation. There scarcely can be a doubt also that the charcoal undergoes decomposition, for after being used five or six years it becomes a coaly earth; and if this be the case, it must yield carbon or carbonic oxide abundantly to the plants growing in it, and thus afford the principal substance necessary for the nutrition of vegetables."*

Liebig is of opinion that the charcoal employed on this occasion undergoes no change, and therefore yields no carbon to the plants; and ascribes the success of these experiments to the great condensing power of charcoal for the carbonic acid in the atmosphere. "And it is by virtue of this power that roots of plants are supplied in charcoal exactly as in humus, with an atmosphere of carbonic acid and air, which is renewed as quickly as it is abstracted." Lucas's observations would lead us to a different conclusion.

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* Buchner's Repertorium, ii Reihe, xix Bd. S. 38.

The opinion of Liebig, that the charcoal employed by Lucas underwent no change, is based upon the indestructibility of this body when prepared from heart-wood of large timbers, which, after having been kept for centuries excluded from the access of the atmosphere, has been found perfectly sound. But it is not so with charcoal made in the ordinary way, from the less valuable parts of timber when kept moist and exposed to the atmosphere. Charcoal of this description undergoes decomposition, and carbonic acid is given off.

Lucas would lead us to infer that this was the case with those experiments which succeeded best; for he says, "In order to ascertain the effects of different kinds of charcoal, experiments were also made upon that obtained from the hard woods and peat, and also upon animal charcoal, although I foresaw the probability that none of them would answer so well as that of pinewood, both on account of its porosity and the ease with which it is decomposed."

The following experiment favors the conclusion drawn by Lucas, and disproves the proposition of Liebig:—

Fifty grains of charcoal, made from elm branches nearly an inch in diameter, was put into a twelve cubic inch bottle whose long neck was graduated into $\frac{1}{100}$ of a cubic inch. To this charcoal was added 400 grains of distilled water: the bottle was tightly corked, sealed, and placed in a green-house on May 26th. It remained in this situation, at a temperature varying from 60° to 90°, until the 6th of July, when the cork was drawn, and 1·1 cubic inch of carbonic acid was removed over mercury by caustic potassa.

The bottle remained open for ten days, when it was corked down and placed in a similar situation, where it stood for 28 days, during which ·58 of a cubic inch of carbonic acid had been formed.

The bottle was again corked, and kept where the temperature varied from 36° to 60°. On drawing the cork, a portion of air made its escape, and there was ·64 of a cubic inch of carbonic acid removed by liquor potassæ.

From these we may conclude, that the charcoal employed by Lucas underwent decomposition, and furnished to the atmosphere carbonic acid; and hence the plants in these experiments might always be in a situation for exercising their influence upon this gas, and for being influenced by it.

That a part of the carbonic acid which was supplied to the plants in Lucas's experiments, was that which the powdered charcoal took up from the atmosphere and again imparted to the plants, will not be questioned; but that all the carbon, which entered into the constitution of these plants during the period of their luxuriant growth, was so taken up, is a very doubtful proposition.

The great facility with which plants appear to remove carbonic acid from the atmosphere, is the best evidence in support of the proposition, that plants derive carbon from that source. If we place healthy plants in a limited atmosphere, containing from three to five per cent. of carbonic acid, and keep them in the sun's rays, the carbonic acid disappears, oxygen is given off, and the plants appear to have improved in their vegetating powers. But if these plants are supplied every four or five hours with fresh carbonic acid, during sunshine, they appear to lose their healthy functions in five or six days, and die sooner than when supplied with the common atmosphere only. If we place plants, whose leaves are inclined to droop, in this mixture of carbonie acid and atmospheric air, the leaves immediately begin to be renovated, and if they are placed where the sun's rays strike upon them, the carbonic acid disappears and oxygen is given off.

The experiments made by Dr. Daubeny, on the property of plants supplying oxygen to the atmosphere, by decomposing carbonic acid,* are amongst the best we have, on that subject, in support of the proposition, *that plants decompose carbonic acid and give off oxygen to the atmosphere.* He placed healthy full-grown plants, and in some instances the branch of the lilac, in a limited atmosphere, under large jars so judiciously arranged that he could at any time supply the plants with fresh carbonic acid, and examine the constitution of the air within the jar. He succeeded, with the branches of the lilac, in raising the proportion of oxygen in the atmosphere to twenty-seven per cent., "which was the maximum of its increase; for at night it sunk to 26, and in the morning exhibited signs of incipient decay. Accordingly in the evening the oxygen amounted only to 26·5; the next evening to 25·5; the following one to 24·75; and the one next succeeding it had fallen to the point at which it stood at the commencement, or to 21 per cent." And he succeeded by introducing several plants into the same jar of air in pretty quick succession, in raising the amount of oxygen contained from 21 to 39 per cent.; and probably had not even then attained the limit to which the increase of this constituent might be brought.

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* Philosophical Transactions, 1836.

These experiments furnish us with abundant evidence in support of the power plants possess, when supplied with an artificial atmosphere, of increasing the quantity of pure oxygen in the atmosphere, but like those already brought forward, they afford no statical proof, that the carbon in the plant was increased by so much only, as was contained in the carbonic acid removed from the atmosphere.

Other experiments, all of which have been conducted with the greatest accuracy, might be added to prove that some plants increase their quantity of carbonaceous matter, independently of organic matter being supplied from the earth or the water in which they grow, and that others abstract carbonic acid from the atmosphere, and give off oxygen gas during sunshine; but these, as well as experiments already mentioned, fall short in proving what proportion of the carbon in plants is derived from these sources.

Without, therefore, detracting from the merits of these experiments, it would probably be more philosophical to suspend our judgment upon this feature in vegetable economy, until we have more inductive evidence brought before us, than to say that "other proof would be superfluous and useless." We proceed, therefore, to inquire in the next place, whether *Carbon in the atmosphere is sufficient for the service of Plants?*

Carbon, in combination with oxygen forming carbonic acid, is a constituent part of the atmosphere; it may be detected by exposing in an open vessel of water holding lime in solution. The carbonic acid combines with the lime and forms a thin covering upon the surface of the water; this may be removed, and the carbonic acid gas which had been abstracted from the air, set at liberty by the application of a dilute acid.

The weight of this acid gas when compared with that of atmospheric air is 1·57 to 1. The proportion which it bears to the other gaseous elements appears to be variable.

| | | Proportion by volume. | Proportion by weight. |
|---|---|---|---|
| Saussure found the | maximum | ·000713 | ·00112 |
| | minimum | ·000322 | ·00051 |
| Dalton | | ·001 | ·00157 |
| Configleachi | maximum | ·008 | ·01257 |
| Humboldt | maximum | ·013 | ·02410 |
| | minimum | ·005 | ·00785 |
| | | Mean . | ·00795 |

On leaving out those by Humboldt, which are probably in excess, we have the mean of the other four, ·00394, and on taking the three first only, we have the mean weight of carbonic acid in the atmosphere ·00107.

It is difficult to ascertain the exact proportion which this gas bears to the other gaseous elements in the atmosphere, the most extensively conducted experiments show that there is more carbonic acid gas in the higher than in the lower regions of the air; that it is in higher proportion during the summer than during the winter months,—that it generally increases during the night, and decreases in the day, and that the atmosphere which surrounds populous districts contains more of this gaseous body than is found in the open country.

That no error may be made in the calculations upon the carbonic acid in the atmosphere, by basing them upon data too high, we shall call the mean proportionate weight ·001 ($\frac{1}{1000}$ part), comprising 27·3 per cent. of its weight of carbon.

The weight of the atmosphere which presses upon each square inch of the earth's surface is upon an average about fifteen pounds. That which presses upon an acre (4,840 square yards—6,272,640 square inches), will be 94,089,600 lbs. containing 94,089 lbs. of carbonic acid, comprising 25,684 lbs. of carbon—as much as is yielded by the dry plants which grow upon the producing land in this country in eight years; and if we regard $\frac{1}{50}$ of the earth's surface as producing vegetables after this rate, the carbon in the atmosphere is sufficient for the service of the plants for 400 years.

Professor Liebig, in his calculations upon this subject, finds, that an atmosphere comprising one-thousandth part of its weight of carbonic acid contains sufficient carbon for the wants of the whole vegetation on the surface of the earth; he says,—"By this calculation it can be shown that the atmosphere contains 3000 billion lbs. of carbon,—a quantity which amounts to more than the weight of all the plants, and of all the strata of mineral and brown coal which exist upon the earth. This carbon is, therefore, more than adequate to all the purposes for which it is required. The quantity of carbon contained in sea-water is proportionally still greater."*

Having found this sufficiency of carbon in the atmosphere, he concludes that the carbon in plants has its origin in the air alone, and instances the critically conducted experiments of Saussure as illustrative of this proposition.

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* Liebig's Agricultural Chemistry, page 22.

The origin of the carbon in plants is of so much importance both in a chemical and agricultural point of view, that before we proceed farther with this subject, let us inquire how far this proposition of Liebig's is supported by these experiments of Saussure.

In Saussure's experimental researches into the variations of carbonic acid in the atmosphere of Chambeisy at mid-day in the years 1827, 1828 and 1829, we have the following as the results for the months of December, January, and February, during which time the atmosphere receives most carbonic acid from sources foreign to plants, and when the earth is bare; and for the months of June, July, and August, when the earth is richly covered with vegetation.

These results are the proportions of carbonic acid in 10,000 volumes of the air experimented upon.

| | | | | | |
|---|---|---|---|---|---|
| 1827, | Jan. 15 | 4·05 | 1827, | July 2 | 5·23 |
| | „ 31 | 3·67 | | „ 7 | 5·43 |
| | Feb. 12 | 3·58 | | „ 20 | 4·74 |
| | | | | Aug. 9 | 5·20 |
| | | | | „ 28 | 4·82 |
| | | | 1828, | June 13 | 4·75 |
| 1828, | Jan. 19 | 4·76 | | „ 26 | 5·09 |
| | Dec. 2 | 4·29 | | „ 28 | 4·46 |
| | „ 5 | 3·95 | | July 7 | 4·81 |
| | „ 22 | 4·18 | | „ 9 | 4·47 |
| | „ 27 | 4·13 | | „ 20 | 4·39 |
| | „ 31 | 4·18 | | Aug. 1 | 4·09 |
| | | | | „ 9 | 4·53 |
| | | | | „ 12 | 4·08 |

| | | | |
|---|---|---|---|
| 1829, Jan. 16 | 4·57 | 1828, Aug. 26 | 4·22 |
| „ 28 | 4·28 | „ 29 | 4·26 |
| Feb. 5 | 4·45 | 1829, June 7 | 4·04 |
| „ 13 | 4·52 | „ 12 | 3·72 |
| „ 19 | 3·66 | „ 17 | 3·80 |
| Feb. 26 | 4·05 | „ 29 | 4·41 |
| Dec. 3 | 3·55 | „ 30 | 4·39 |
| „ 7 | 3·50 | July 8 | 4·35 |
| „ 15 | 3·74 | „ 15 | 4·15 |
| „ 18 | 4·04 | „ 25 | 4·45 |
| „ 24 | 3·36 | Aug. 8 | 3·22 |
| „ 26 | 4·22 | „ 19 | 3·44 |
| „ 30 | 3·66 | „ 22 | 3·85 |
| | | „ 31 | 4·30 |
| Mean | 4·01 | Mean | 4·38 |

The experiments made in the years 1816—1820, gave for the mean proportion of carbonic acid in 10,000 parts by volume in the winter months 3·99, and in the summer months 5·33 parts.

The proportion of carbonic acid in these experiments for the summer months is, 4·38 parts in 10,000. When the plants which then cover the earth are apparently daily removing from the atmosphere carbonic acid gas, the proportion of this gas in the atmosphere for the winter months is 4·01 in 10,000 parts, when the summer produce has been removed from the fields; and in the course of various changes, much of its carbon has found its way into the atmosphere in the shape of carbonic acid.

These experiments giving 4·38 for the proportion of carbonic acid gas in the atmosphere during the summer months; and 4·01 for that in the winter months, being an excess of ·37 in 10,000 parts by volume equal to ·58 parts by weight in favour of the former season. On calculation, this excess will be found to amount to 5,456 lbs. of carbonic acid gas, comprising 1,400 of carbon for the volume of air resting upon each acre of land.

Supposing that the earth produces vegetables after the rate of two tons annually per acre of one-fiftieth part of the surface, this increase of carbon during the summer months of one year, is more than the land would produce in forty years. From what source then do the plants which grow upon the land between February and August derive their carbon? Not from the atmosphere, because the quantity is not diminished, but prodigiously increased during that season. They cannot extract it all from the earth, for the best land which produces most plants loses least carbon in producing them. They cannot have derived it from the organic matter in the inferior land, because in this case the land does not contain sufficient to sustain its vegetation and to supply the air. The very bad land which is richly manured may supply its plants with carbon, and afford a small portion for the carbonic acid of the atmosphere. But whence comes the surplus carbon in the carbonic acid found in the atmosphere? Its accumulation in the atmosphere during the summer months cannot be satisfactorily accounted for, on the supposition that it has been brought by the winds from one quarter of the globe to another. It would therefore seem that De Saussure's experiments so far from favouring the theory that the carbon in plants has its origin in the carbonic acid in the atmosphere, afford grounds for a very different conclusion, viz., that the carbon in plants is principally derived from some other source.

In further support of this conclusion, we shall adduce other experiments conducted by De Saussure, which we prefer both for their intrinsic value, and because Professor Liebig brings them so prominently forward in support of his theory.

On the 7th and 8th of August, and on the 29th and 30th of September, De Saussure experimented on air collected on the Col de la Faucille, 963 feet above Lac Léman, at 11 P.M.; and at the same time on that taken at Chambeisy, four feet from the ground. These gave for the air on the mountain, a mean of 3·95 volumes of carbonic acid in 10,000 of the air; for that on the plain, 3·71. From the air taken on the following day at noon, he obtained from that on the mountain 3·77; from that on the plain, 3·18; shewing a difference in the proportion of carbonic acid in the night and the following day of ·18 for the air on the mountain, and ·53 for that on the plain.

The mean atmospheric pressure at the surface of the earth, is considered equal to the support of a column of mercury 30 inches high.

| | |
|---|---|
| At 1,000 ft. above the surface, the column falls to | 28·91 |
| 2,000 .. .. .. .. .. | 27·86 |
| 3,000 .. .. .. .. .. | 26·85 |
| 4,000 .. .. .. .. .. | 25·87 |
| 5,000 .. .. .. .. .. | 24·93 |
| 1 mile .. .. .. .. .. | 24·67 |
| 2 „ .. .. .. .. .. | 20·29 |
| 3 „ .. .. .. .. .. | 16·68 |
| 4 „ .. .. .. .. .. | 13·72 |
| 5 „ .. .. .. .. .. | 11·28 |
| 10 „ .. .. .. .. .. | 4·24 |
| 15 „ .. .. .. .. .. | 1·60 |
| 20 „ .. .. .. .. .. | 0·95 |

1,000 feet of the lower regions of the atmosphere, according to this table, is 3·63 per cent. of the entire weight; and if we take the mean of Saussure's experiments $\left(\frac{\cdot 18+\cdot 53=}{2}\right)$ ·355 by volume, ·543 by weight, as the carbonic acid which disappeared from the atmosphere, between the hours of eleven at night and twelve the following day, and calculate for this being an effect produced by plants only upon 1,000 feet of the lower regions of the atmosphere; we have the plants upon each acre of the cultivated land increasing their carbon 60 lbs. in seven hours. And if we take into account that portion of carbonic acid which would be imparted to the atmosphere by plants between 11 P.M. and sun-rise on the following day, the quantity which disappeared would considerably exceed 60 lbs.

If it be true that plants, rain, snow, &c. are the only means by which carbonic acid is removed from the atmosphere, the plants, during the interval of each of these two sets of experiments, must have been the only operative agents, as the weather was calm and clear at the different times when the above experiments were made. If, under these circumstances, we make our calculations for ascertaining the truth of the proposition under consideration, and suppose that one half the surface of the earth in that district was richly clothed with plants, and was producing abundant crops, we may safely say that the carbon which disappeared from the atmosphere between sunrise and sun-set, was equivalent to 100 lbs.—one twenty-fourth of an abundant year's produce.

On taking the experiments of the same philosopher, made on the 26th of August, 1828, when the weather was clear, and in every respect favourable for vegetation; and calculating for the proportions of carbonic acid bearing the same ratio at the height of 1,000 feet, as those above-mentioned, we have the results conversely to a much greater extent.

These experiments, which were made upon air collected four feet from the ground, at Chambeisy, are given as under.

| Date. | Time. | Temperature. Fahrenheit. | Wind, Sky, &c. | Carbonic Acid in 10,000 vols. |
|---|---|---|---|---|
| Aug. 26 | Midday | 71° | Moderate. Clear. Earth moist. | 4·22 |
| | 4 P.M. | 71° | do. | 4·20 |
| | 8 P.M. | 67° | do. Light dew. | 4·76 |
| | Midnight | 52° | do. | 4·69 |
| 27 | 3½ A.M. | 50° | Calm, clear, dewy. | 5·74 |

The mean proportion of carbonic acid between 4 P.M. and 8 P.M. is 4·76—4·20 = ·56; and that between 8 P.M. and 3½ A.M. on the following day, 5·74—4·76 = ·98; the former giving for the mean at 1,000 feet high, according to the former ratio, ·38, and the latter ·66 parts, in 10,000 volumes.

These give for the weight of carbon imparted to the atmospheric column 1,000 feet high, resting upon each acre of land between the hours of 4 P.M. to 8 P.M., 64 lbs.; and between 8 P.M. and 3½ A.M. on the following morning, 111 lbs. more; making a total of 175 lbs. And upon the supposition that this was an effect produced by plants which grew upon every one out of two acres of the earth's surface in this district, the carbon given off by the plants, during the periods under consideration, would be twice the above amount,—350 lbs., equal to one-ninth of a very abundant year's produce ; consequently, if only half this quantity were given off by plants during twenty-four days of cloudy weather, our most productive land, during a season, which we know to be most favourable to vegetation, would become as destitute of plants as the barren rock or the sandy desert.

If we refer to practical experience, it is well known that plants which grow in partially shaded situations, increase more in size, and when dry, are of greater weight, than those which are most exposed to the sun ; and experiments teach us that plants growing in these shaded situations are constantly giving off carbonic acid to the atmosphere, in larger quantities than those which grow under the more direct influence of the sun's rays. From whence, then, did their carbon proceed? Not from the atmosphere.

Whether, therefore, we take the evidence of Saussure's experiments, or that of general experience, we find no proof that plants derive much of their carbon from the carbonic acid in the atmosphere.

Still, taking De Saussure as our guide with respect to the carbonic acid in the atmosphere, during the winter and summer months respectively, we find that during the latter, there is more carbonic acid in the air than during the former.

The eighty-two experiments made upon the air collected during the months of October, November, December, January, February, and March, in the years 1827, 1828, and 1829, gave for the mean proportion of carbonic acid 4·02 in 10,000 parts ; and in the eighty-four experiments upon that collected during the other six months, 4·46 parts ; making a difference of ·44 parts by volume, equal to ·64 parts by weight; and containing, throughout the whole height of the atmosphere, 1,126 lbs. of carbon per acre; as much as is comprised in 3,000 lbs. of corn and straw in the condition in which they are carried from the field.

On taking the proportion of carbonic acid found in the atmosphere, during the three cold months preceding and subsequent to each of the six months more favourable to the growth of plants, we have the following for the proportion:—

| | |
|---|---|
| During Apr. May, June, July, Aug. & Sept. 1827 | 5·377 |
| „ the cold months before and after summer | 4·296 |
| Increase . . . | 1·081 |
| During Apr. May, June, July, Aug. & Sept. 1828 | 4·65 |
| „ the cold months before and after summer | 4·10 |
| Increase . . . . | ·55 |
| During Apr. May, June, July, Aug. & Sept. 1829 | 4·04 |
| „ the cold months before and after summer | 3·91 |
| Increase . . . . | ·13 |

These experiments lead us to infer that plants, during the summer months, impart more carbonic acid to the atmosphere than they remove from it. Now as there is a far greater accumulation of vegetable matter upon the surface of the earth in the summer than in the winter months, it would appear that the carbon in the atmosphere is increased with the increase of organic matter on the earth's surface; and we are naturally led to inquire whether the carbonic acid given off by plants is equivalent to that which is found in the atmosphere.

Sir Humphry Davy found, when he examined his experiments made by placing within glass shades turfs clothed with grass, principally meadow foxtail, that the carbonic acid in the air within the shade was increased.* Similar results were obtained when the shoot from a vine was made the subject of experiment.

Mr. Burnett, from his experimental investigations on this subject, drew the conclusion that there is an increasing formation of carbonic acid by day and by night in air which surrounds living vegetables.†

From these investigations, and especially from those by Mr. Burnett, an increase of carbonic acid in the atmosphere seems to be a necessary consequence of the growth of plants. But the works of these vegetable physiologists, give us little information as to the volume of carbonic acid in the atmosphere, compared with that given off by the living vegetables, a point, which it is exceedingly difficult to ascertain by experiment.

If we make experiments upon plants growing in pots, or in clumps of earth, and place them in a limited atmosphere under glass shades, and examine from time to time the constitution of the air which surrounds them, we invariably find an increase of carbonic acid gas. But, even when the experiment is thus made, we cannot determine how far this increase of carbonic acid is the result of the elaboration of the plants, or how far of the chemical changes which the organic matter contained in the soils is undergoing, and which change is promoted by the increase of temperature occasioned by the glass shades. It may also be added, that in preparing, conducting, and examining experiments of this kind, we have no method by which we can determine the comparative quantity of carbon in the plants and in the soil, both at the commencement and at the conclusion of any experiment.

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* Davy's Agricultural Chemistry, 4to. page 196.

† Journal of the Royal Institution, page 95.

The experiments which afforded me the most satisfactory evidence upon the quantity of carbonic acid given off by plants to the atmosphere, were made with seeds planted in earth entirely free from organic matter. These were placed within glass shades, surrounded by water which cut off external atmospheric communication. The air within the shades was examined every five, six, or seven days. These seeds germinated, and the young plants remained in a healthy condition for forty, fifty, or sixty days, and in some instances for three months; the time varying with the kind of plants, and with the temperature at which they were kept. It is necessary in experiments of this kind, to allow the seeds and plants considerable space within the glass shade under which they are to germinate and grow. In a long course of experimenting, I have found that when 100 grains of farinaceous seeds, and from 20 to 30 grains of such seeds as turnip, rape, mustard, cress, &c., have an atmosphere of not less than 400 cubic inches in which they are to germinate and grow, the progress which they make is frequently greater, than if they had been kept in the open air.

The following is an example of this kind:—The experiment was made with fine red wheat. 100 grains (126 seeds) of this wheat, containing 40·1 per cent. of its weight of carbon, was planted in a mixture of equal parts of burned clay and sand in fine powder, weighing 2 lbs., and moistened with distilled water. This experiment was placed within a glass shade of 446 cubic inches, and kept in a room not artificially heated, where the sun shone about one half the day.

February 8th commenced the experiment.

| | | Increase of Carb. Acid. Cubic Inches. | Condition of Plants. |
|---|---|---|---|
| Feb. | 15th—8 A.M. | 15·1 | |
| | 22d—7 A.M. | 33·2 | Plants three inches in length. |
| March | 1st—7 A.M. | 17·8 | |
| | 8th—7 A.M. | 13·8 | |
| | 15th—7 A.M. | 13·1 | Plants 6 inches high. |
| | 22d—7 A.M. | 16·4 | The ends of some of the leaves yellow, the plants cut off by the earth. |
| | 29th—7 A.M. | 24·8 | Each plant shews signs of vegetation. |
| April | 5th—6 A.M. | 15·2 | The young shoots about an inch in length. |
| | 12th—6 A.M. | 19·0 | |
| | 19th—7 A.M. | 11·8 | The young plants healthy. |
| | 26th—6 A.M. | 17·8 | |
| May | 3rd—6 A.M. | 13·4 | Plants have made little progress during the last week. |
| | 6th—6 A.M. | 6·4 | Some of the leaves are dead. |
| | | 217·8 | |

The plants, which were cut close to the earth March 29th, weighed, when dry, 27·6 grains; those cut May 6th weighed 9·2 grains. Together they weighed 36·8 grains, and contained 14·9 grains of carbon. The 217·8 cubic inches of carbonic acid, which had been given off to the surrounding air, would contain 28·4 grains of carbon.

This experiment gives for the carbon in the carbonic acid, March 29th, 17·5 grains, and that in the plants 11·1 grains. On the 6th of May, that in the carbonic acid 10·9 grains, and that in the plants 3·8 grains; so that both in the former and latter part of the experiment, the carbon in the carbonic acid exceeded that in the plants above the ground.

This emission of carbonic acid during vegetation, appears to bear a direct proportion to the growth of the plants. Those plants which increase their quantity of carbon most, gave off to the surrounding atmosphere most carbonic acid. Two other experiments, conducted under circumstances similar to the one described, did not grow so luxuriantly; one of these gave for the carbon in the carbonic acid, March 29th, 15·8 grains, that in the plant 10·2 grains; the other gave for the carbon in the carbonic acid 15·6 grains, and for that in the plants 10·1 grains.

Experiments in which barley instead of wheat was employed gave similar results: the carbon in the carbonic acid, when removed every four, five, or six days, exceeded that in the plants by one-third. In the experiments made with turnips, rape, mustard, and cress, the carbon in the carbonic acid, when removed every fourth day, the plants being kept at a temperature varying from 50° to 65°, more than doubled that in the young plants; and in two experiments upon turnip seed, kept partially in the shade, the quantity of carbon removed from the atmosphere, exceeded that in the seeds planted.

When the carbonic acid is removed every second day, during the early growth of the plants, the quantity of carbon in the acid, when compared with that in the vegetables, bears a still higher proportion. When it is removed in the evening, after the plants have been exposed to a bright sunshine, the carbon in the carbonic acid generally exceeds that in the plants, though in a less degree.

An experiment on wheat seeds, from the sample above-mentioned, conducted in the same way, except that the carbonic acid was removed in the evening, instead of the morning, gave for carbon in the acid 16·4 grains; in the plants 15·8 grains.

Other modes of experimenting favor the same conclusion. If a sprig of mint is placed in water, and kept exposed to the sun's rays, under a glass containing 1000 cubic inches of atmospheric air, all external communication being cut off by water, the plant grows more luxuriantly than when kept in the open air; and the proportion of carbonic acid in the confined atmosphere is increased.

Experiments more resembling the ordinary course of vegetation, give similar results. A turf, three by four inches, clothed with short grass; and a strawberry plant, containing fourteen small leaves, growing in a poor soil four inches square, were kept at a temperature varying from 55° to 65°, and placed in the night under glass shades, whose dimensions were from 400 to 410 cubic inches; atmospheric communication cut off by water. During the day the shades were removed. At the conclusion of the experiments not one faded leaf was to be seen, the plants were in a more healthy condition, and had made greater progress in growth than similar plants which were always kept exposed.

| | | Carbonic acid given off. Cubic inches. | Proportion of carbonic acid in 10,000 part of the atmosphere 1000 ft. high. | Proportion of carbon when compared with that in an abundant annual crop. |
|---|---|---|---|---|
| The turf experiment. | First night | 7·3 | ·496 | 3·1 per cent. |
| | Second do. | 8·4 | ·580 | 3·6 „ |
| | Third do. | 12·6 | ·863 | 5·4 „ |
| | Fourth, after remaining uncovered 6 nights | 7·5 | ·510 | 3·3 „ |
| | Fifth night | 6·1 | ·418 | 2·6 „ |
| | Sixth do | 8·3 | ·572 | 3·7 „ |
| | Seventh, after remaining 5 days uncovered | 8·4 | ·580 | 3·6 „ |
| | Eighth night | 6·0 | ·41 | 2·6 „ |
| | | | | 3·5 mean |
| The strawberry experiment. | First night | 14·0 | ·714 | 4·4 „ |
| | Second do. | 9·2 | ·470 | 2·9 „ |
| | Third do. | 13·6 | ·693 | 4·3 „ |
| | Fourth do | 10·4 | ·53 | 3·3 „ |
| | Fifth, after being uncovered 6 days | 9·8 | ·50 | 3·1 „ |
| | Sixth night | 11·6 | ·591 | 3·6 „ |
| | Seventh, after being uncovered 8 days | 11·5 | ·59 | 3·6 „ |
| | Eighth night | 13·8 | ·70 | 4·3 „ |
| | | | | 3·7 mean |

If we examine the atmosphere of hot-houses in which the stems and leaves of vines alone are growing, the roots being outside, though the stems and leaves in the inside increase their quantity of carbon abundantly, the proportion of carbonic acid within exceeds that in the external atmosphere. These facts shew that plants during the healthy performance of their functions in the ordinary course of vegetation, impart to the surrounding atmosphere more carbonic acid than they take from it; and taken in conjunction with the luxuriant growth of plants during the summer, compared with the slow growth in the winter months, account for what Saussure found by experiment, viz., that the quantity of carbonic acid in the atmosphere during the summer months, was much greater than during the months less favourable to vegetation. But they furnish us with no data, from which we can ascertain the comparative quantity of carbon which enters into the constitution of those plants which clothe our fields and gardens, and that in the carbonic acid imparted to the atmosphere.

## PRODUCTION OF CARBON BY PLANTS.

The increase of carbonic acid in the atmosphere keeping pace with the increase of vegetable matter on the earth's surface, suggests the idea, that instead of plants deriving all their carbon from the atmosphere, the atmosphere derives its carbon from plants, and that plants make carbon. I shall endeavour to establish this position by further experimental evidence.

If plants or seeds are placed where they can extract little or no carbon from foreign sources, and if the weight of their carbon at the conclusion of the experiment exceeds the combined original weight of their carbon, and of the carbon in any source within their reach, there is a positive gain of carbon; and the growth of the plants would seem to be the only agency by which it could have been produced.

The first experiment which I shall adduce is a very simple one. It was made with sprigs of mint. The lower leaves were cut off close by the stems, leaving eight small leaves at the top of each. Two other sprigs, weighing fifty grains, were dried, at a temperature not exceeding 130°, when their weight, after twenty-four hours' exposure, was 7·08 grains, and constituted of

| | | |
|---|---|---|
| Carbon | 41·74 | 2·96 |
| Hydrogen | 5·19 | 0·37 |
| Oxygen | 38·76 | 2·74 |
| Nitrogen | 2·31 | 0·16 |
| Ashes | 12·00—100 | 0·85—7·08. |

Two other sprigs, of the same weight, were put into a four-ounced crown glass bottle, which was filled nearly to the neck with river water, containing not more than $\frac{1}{3}$ grain of organic matter, and about half a grain of earthy matter. This bottle, together with a tube graduated in $\frac{1}{500}$ of a cubic inch, was placed on a large plate, and covered with a glass shade, whose content was 410 cubic inches. Atmospheric communication was cut off by water, which lay half an inch in depth upon the plate. The experiment was fitted up in the month of May, and placed in the open air, where it was exposed to the sun's influence till 3 p.m. The vegetating progress of these plants appeared to be little affected by cutting them from roots growing in the earth, and placing them in this kind of water; new leaves formed at the top of each plant from the first. On the seventh day, two of the lower leaves began to droop, and small roots made their appearance from the apex where the lower leaves had been broken off. The two drooping leaves were removed on this day, and the apparatus fitted up as at the commencement. The plants continued to thrive, and their leaves and roots increased in number until the twenty-eighth day, at which period the experiment was terminated. The atmosphere was changed four times; at each time the quantity of carbonic acid given off was ascertained. It was as follows:—

| | | | | |
|---|---|---|---|---|
| On the | 5th | day | 3·0 | cubic inches. |
| ,, | 10th | ,, | 3·2 | ,, |
| ,, | 15th | ,, | 2·9 | ,, |
| ,, | 22nd | ,, | 3·3 | ,, |
| ,, | 28th | ,, | 3·1 | ,, |
| | | Total | 15·5 | |

The plants, without the leaves which had been removed, weighed, when taken from the water, 116 grains. When dried at 130°, and exposed for twenty-four hours, their weight, including the leaves which had been removed, was 14·8 grains, constituted of

| | | |
|---|---|---|
| Carbon ...... | 40·8 ...... | 6·04 |
| Hydrogen .... | 5.8 ...... | ·86 |
| Oxygen ...... | 43·5 ...... | 6·44 |
| Nitrogen...... | 1·9 ...... | ·28 |
| Ashes........ | 8·0—100 | 1·18—14·8 |

The water in the bottle, and on the plate, contained carbonic acid. There was a formation of green vegetable matter on the plate, and on the inside and outside of the glass shade. There was a similar matter at the bottom of the bottle, which exceeded the quantity contained in the water at the commencement. The organic matter held in solution by the water was increased to nearly double that of the original quantity.

The comparative weight of the plants dried after vegetation, and the weight of those sprigs which were dried at the first was—

| | |
|---|---|
| Dry plants after 28 days' vegetation . | 14·8 grains. |
| Sprigs dried at the commencement . | 7·08 |
| Increase . | 7·72 grs. |

equal to 109 per cent.

This experiment shows a positive gain of carbon, the amount of which may be thus calculated:

| | | Grains. | Grains. |
|---|---|---|---|
| After vegetating for 28 days . | carbon in the plants . . | 6·04 | |
| | in the water, say . . . . | ·13 | |
| | at the bottom of the bottle say . . . . . . . . | ·15 | |
| | in the carbonic acid . . | 2·02 | 8·34 |
| At the commencement. | carbon in the two plants . . . . . . . . . . | 2·96 | |
| | in the water, say . . | ·13 | 3·09 |
| | Grains increase | | 5·25 |

equal to 170 per cent.; a gain, or increase of carbon which, under the circumstances, can only be accounted for on the supposition that plants make carbon.

As several experiments will, in the course of the inquiry be ranged under various heads, proving that plants make carbon during vegetation, one or two others only will be given here. In the one already described we have an instance of the cuttings of tender herbs making carbon during their growth. The following was made with seedling plants, and is equally conclusive. The seed used was the same kind of wheat seeds mentioned in page 56. Before the experiment the sample was kept in a dry room for several weeks; it was afterwards inclosed in stoppered bottles. In 1000 grains by weight of the average sample there were 1,321 seeds, making the average for each seed ·7576 of a grain. In 1000 grains, from which the smaller seeds had been removed, there were only 1,205 seeds, making the average of these ·8298 of a grain. The specific gravity of the average sample when first placed in water was 1·3158—water being 1; and when it had been under water twenty-six hours at 50°, its specific gravity was 1·3513. The chemical constitution of the seeds, husks, and flour when reduced to a powder was

| | |
|---|---|
| Carbon | 40·24 |
| Hydrogen | 6·70 |
| Oxygen | 50·12 |
| Nitrogen | 1·22 |
| Ashes | 1·72 |
| | 100· |

The experiment with seeds of this wheat was prepared and conducted in the following manner: portions of clean silicious sand and clay were separately kept at a red heat in a crucible for nearly an hour. A mixture of half a pound of each of these was made, and washed in dilute sulphuric acid. No effervescence ensued, showing that no carbonic acid was present. This mixture was repeatedly washed in water, dried, and again exposed to a red heat. A portion of it was subjected to analysis with black oxide of copper: no carbonic acid was given off. The mixture of the two earths was then regarded as entirely free from carbon, either in an organic, or in an inorganic state.

The mixture thus prepared was put into a common flower-pot, and placed in a saucer containing distilled water, when the earth was in a state of moisture favourable for the germination of seeds and the growth of plants; sixty-three seeds, weighing fifty grains, were planted in this moistened earth, about half an inch from the surface. The flower-pot and saucer were placed on a plate. Two finely graduated tubes were laid over the pot. A jar whose content was 216 cubic inches covered the whole, and atmospheric communication was cut off by mercury, on the surface of which was water lying about half an inch in depth.

The experiment was fitted up October 31st, and placed in an apartment not artificially heated, and in a situation where the sun shone about one-third of the day. At each time of the examination, the air in the graduated tube was tested for the proportion of carbonic acid in the experiment. The jar was filled with fresh atmospheric air and replaced. The following is the registered account of the experiment. In the column under carbonic acid, is the volume of this gas which was given off by the plants, after making an allowance for that in the atmosphere with which the experiment was supplied.

| Date. | Carb. acid given off by seeds and plants. | Condition of plants. |
|---|---|---|
| Nov. 9, 8 A.M. | 13·8 cub. in. | plants making appearance. |
| 16 „ | 18·4 „ | do. an inch in length. |
| 24 „ | 14·2 „ | do. 3 in. long with 2 leaves |
| Dec. 2 „ | 16·5 „ | |
| 11, 2 P.M. | 12·6 „ | do. 8 inches long. |
| 24 „ | 6·7 „ | |

| Date. | Carb. acid given off by seeds and plants. | Condition of plants. |
|---|---|---|
| Jan. 4, 2 P.M. | 7·2 cub. in. | plants 10 inches long. |
| 18 ,, | 7·0 ,, | some of the leaves yellow. |
| 25 ,, | 6·4 ,, | many of the plants are in a state of decay. Exp. broken up. |

102·8 cubic inches, containing 13·4 grains of carbon.

The plants were cut off near to the earth, dried at a temperature not exceeding 120°, exposed to the atmosphere for twenty-four hours, when their weight was 17·3 grains, and constituted of

| | | |
|---|---|---|
| Carbon | 42·0 | 7·27 |
| Hydrogen | 5·1 | ·88 |
| Oxygen | 42·6 | 7·37 |
| Nitrogen | 2·5 | ·44 |
| Ashes | 7·8 | 1·34 |
| | 100· | 17·3 |

The contents of the flower-pot were spread on a large plate, and exposed to a temperature not exceeding 120°. On the water evaporating, the roots, the remaining part of the stems, and husks of the seeds were readily separated from the earth; the particles of clay and sand which adhered to them were removed by passing them through fine muslin. The earth which contained the smaller roots was dried, and passed through a fine sieve. The small roots and coarse powder were collected, folded in muslin, and gently rubbed. The earthy particles being reduced to a fine powder, were passed through the muslin, and the small roots remained in the fold.

These roots, parts of stems, and husks, weighed 25·8 grains, and were constituted of

| | | |
|---|---|---|
| Carbon | 34·1 | 8·8 |
| Hydrogen | 4·3 | 1·1 |
| Oxygen | 34·5 | 9·0 |
| Nitrogen | 1·1 | ·3 |
| Ashes | 26·0 | 6·6 |
| | 100· | 25·8 |

A perfect mixture of the earth was made, and a portion of it subjected to analysis with black oxide of copper: this gave for the quantity of carbon in the whole 4·6 grains.

On comparing the weight of the carbon in the carbonic acid, the plants and the earth, with that in the seeds at the commencement of the experiment, we have

| | | |
|---|---|---|
| Carbon in the carbonic acid | 13·43 | grains. |
| Do. in the plants | 7·27 | „ |
| Do. in the roots, husks, &c. | 8·80 | „ |
| Do. in the clay and sand | 4·6 | „ |
| Total | 34·10 | |
| Carbon in the seeds planted | 20·12 | |
| | 13·98 | grs. increase |

of carbon, equal to 69·5 per cent.

Exclusive of the carbon in the carbonic acid, the carbon in the plants, roots, husks, and the earth, is 20·67 grains, being an increase of ·55 of a grain, equivalent to 2·7 per cent. only.

These experiments not only show that plants make carbon, but that they make it in very different proportions.

In drawing a comparison between the quantity made by the sprigs of mint, and the seedling wheat plants, we have in the comparison, without the carbonic acid gas,

An increase of carbon in the mint, 109 per cent.

| | |
|---|---|
| Do. in the wheat seeds, including plants, roots, husks, and seeds, and that which was deposited in the earth .... | 2·7 per cent. only |

And it very generally happens that in experiments made with seeds, their different parts, taken collectively, shew no increase upon the original quantity contained in the seeds, but the contrary. On the comparison, including the carbonic acid, we have—

| | |
|---|---|
| Increase upon the mint...... | 170 per cent. |
| Do. upon the wheat seeds | 69·5 do. |

Shewing that the principal increase in the experiments upon the seedling plants is in the carbonic acid imparted to the air.

To these experiments may be added the two following, which more resemble what may be supposed to occur in our fields. The first was made with a turf from a strong clayey soil, which had not been manured for many years, until three months previous to its being taken from the ground, where it was twice watered with a mixture composed of one-third urine and two-thirds water. That turf was four inches by eight, and about four deep, uniformly clothed with grass, which was cut close to the surface. This turf was divided into two portions, each having a superficial area of ten square inches, and weighing 5,000 grains. One portion was immediately dried, and kept in that state; the other was put into a flower-pot, which stood on a saucer resting in a large dish containing water.

This experiment was placed in a vinery kept at a temperature varying from 58° to 78°. During the night it was covered with a glass shade, whose content was 400 cubic inches, which was removed every morning before sunrise, when a portion of the air was examined. The experiment was thus kept about half the time under a glass shade, and the other half of it was exposed to the uninterrupted influence of the atmosphere of a well-ventilated vinery. It was supplied with rain water every third day. The grass grew freely all the time, with scarcely a fading leaf. The following is a copy of the registered account of this experiment. One column represents the volume of carbonic acid removed from the air within the shade, after deducting that in the atmosphere, when it was inclosed; the other represents the proportion which this volume of carbonic acid bears to that of an atmosphere 10,000 feet high.

| No. of day. | Vol. of Carbonic Acid in Cubic Inches. | Vol. in 10,000 of air, 1,000 feet high. | No. of day. | Vol. of Carbonic Acid. | Vol. in 10,000 of air, 1,000 feet high. |
|---|---|---|---|---|---|
| | | Parts. | | | Parts. |
| 1 | 13·0 | 1·083 | 22 | 8·1 | ·675 |
| 2 | 10·5 | ·875 | 23 | 6·0 | ·50 |
| 3 | 8·6 | ·717 | 24 | 7·4 | ·617 |
| 4 | 9·1 | ·758 | 25 | 13·1 | 1·092 |
| 5 | 10·0 | ·833 | 26 | 11·2 | ·925 |
| 6 | 12·8 | 1·067 | 27 | 10·0 | ·833 |
| 8 | 9·6 | ·800 | 29 | 5·3 | ·442 |
| 9 | 10·8 | ·900 | 30 | 8·4 | ·700 |
| 10 | 11·6 | ·967 | 31 | 6·2 | ·517 |
| 11 | 8·0 | ·667 | 32 | 9·6 | ·80 |
| 12 | 11·8 | ·983 | 33 | 6·6 | ·55 |
| 13 | 6·0 | ·500 | 34 | 6·0 | ·50 |
| 15 | 10·7 | ·892 | 36 | 7·2 | ·60 |
| 16 | 5·0 | ·417 | 37 | 3·3 | ·292 |
| 17 | 11·1 | ·925 | 38 | 10·2 | ·85 |
| 18 | 12·4 | 1·033 | 39 | 13·8 | 1·15 |
| 19 | 10·1 | ·842 | 40 | 11·7 | ·975 |
| 20 | 10·6 | ·883 | 41 | 6·4 | ·533 |

The entire volume of carbonic acid imparted to the atmosphere by the grass upon this turf, is 332·2 cubic inches, containing 43·4 grains of carbon; and if to this we add for the six nights during which it was not covered 5·6 grains, we have the weight of carbon given off during the six weeks 49 grains.

The grass was cut on the 41st day, and when dry weighed 18·8 grains, and was constituted of—

| | |
|---|---|
| Carbon | 7·04 |
| Hydrogen | 1·18 |
| Oxygen | 8·76 |
| Nitrogen | ·88 |
| Ashes | ·94 |
| | 18·8 |

The earth was taken from the flower-pot, and dried; its weight was then 4,200 grains; portions of it and that of the original sample were subjected to repeated analysis. These gave for the weight of carbon:—

| | Per Cent. | Equal to |
|---|---|---|
| In the earth from the flower-pot | 5·7 | 239 grains in all. |
| Do. original sample | 5·3 | 223 do. |

On a recapitulation of the carbon in this experiment we have—

| | |
|---|---|
| Carbon in the carbonic acid given off, | 49 |
| Do. in the grass produced | 7 |
| Do. left in the earth | 239 |
| | 295 grains. |
| Originally in the earth | 223 do. |
| Increase | 72 |

Being equal to 32 per cent. on calculating for the carbon in the carbonic acid imparted to the atmosphere; and independently of this, the increase is equivalent to 10 per cent.

In this experiment we have three very important features in vegetable economy brought before us;—first, carbonic acid is a constant but variable product, emanating from the growth of grass during the night: a feature which has been more fully noticed in the preceding chapter;—secondly, carbon is a vegetable product, made by the grass plant in very considerable quantities;—thirdly, when land is brought into a fertile condition by the addition of foreign bodies, such land appears to be enriched in carbon by producing plants.

The other experiment was made with a turf from a gravelly soil, which had been so affected by the continued dry weather, that there was scarcely a green blade of grass upon it. This turf was three inches square, about two inches thick, and weighed 4,000 grains. It was placed, and the experiment conducted under circumstances similar to the last mentioned, with the following exceptions. The former was kept in a vinery; this was kept in the open air, and in a situation where the sun shone from 7 A.M. till sunset, during which period it was uncovered. It was covered with the glass shade from sunset till 7 A.M., when the atmosphere was examined; and when required, the turf was supplied with rain water. The following is a copy from the registered account of the experiment:—

| Date. | Vol. of Carbon. Acid. | Vol. in 10,000 of air, 1,000 ft. high. | REMARKS. |
|---|---|---|---|
| | Cub. In. | Parts. | |
| June 14 | 12·5 | 1·042 | Night sultry; no rain. |
| 15 | 7·1 | ·592 | Day thunder; night clear; no rain. |
| 16 | 4·5 | ·375 | Day cloudy; night fine and clear; dew. |
| 17 | 8·2 | ·683 | Day cold; night clear and calm, dew. |
| 18 | 7·4 | ·616 | Day cloudy, no rain; night cold, light dew. |
| 19 | 6·8 | ·567 | Day light rain; night light showers. |
| 20 | 6·0 | ·500 | Day thunder, light rain; night rain. Grass growing freely. |
| 21 | 5·9 | ·492 | Day partial sunshine; night calm & cloudy. Turf thinly covered with common grass. |
| 22 | 5·7 | ·475 | Day clear & bright; night calm, heavy dew. |
| 23 | 2·6 | ·217 | Day bright sunshine; night light breezes. |
| 24 | 3·4 | ·267 | Day wind & sunshine; night cloudy & rain, |
| 25 | 6·6 | ·550 | Day cloudy and light rain; night fine. light dew. |
| 26 | 3·0 | ·250 | Day cloudy, wind; night wind, cloudy. Turf remains thinly clothed with grass. |
| 27 | ·8 | ·067 | Day wind, sunshine; night high wind. |
| 28 | ·6 | ·050 | Day bright sunshine; night calm, dew. |
| 29 | ·6 | ·050 | Day do. do. do. |
| 30 | 1·6 | ·137 | Day do. night light wind. |
| July 1 | 6·4 | ·537 | Day cloudy and light showers; night much rain. |
| 2 | 2·0 | ·162 | Day light rain; night a little rain. Grass grows freely. Turf thinly covered. |
| 3 | 4·6 | ·383 | Day fine; night cloudy. |
| 4 | 4·9 | ·408 | Do. do. |
| 5 | 4·8 | ·400 | Do. night windy. |
| 6 | 3·9 | ·325 | Day showery; night clear and bright. |
| 7 | 4·2 | ·350 | Day fine and clear; night do. |
| 8 | 5·4 | ·45 | Day light showers; night calm & cloudy |
| 9 | 7·1 | ·592 | Do. do. heavy rain. |
| 10 | 4·2 | ·350 | Do. do. fine and clear. Plants turning yellow, owing to being too wet. |
| 11 | 10·1 | ·892 | Day fine; night light showers. |
| 12 | 7·0 | ·582 | Day bright sunshine; night fine & clear. |
| 13 | 6·2 | ·513 | Do. do. Plants reviving. Experiment discontinued. |
| | 154·1 | | |

On examination, the bottom of the turf was found covered with a thin matting composed of fine roots; which, on being separated and dried, weighed 10·2 grains, and were constituted of

| | | |
|---|---|---|
| Carbon | 30·5 | 3·11 |
| Hydrogen | 4·8 | ·49 |
| Oxygen | 34·1 | 3·48 |
| Nitrogen | 3·3 | ·34 |
| Ashes | 27·3 | 2·78 |
| | 100 | 10·2 |

On comparing this turf when dried, with a sample of the original turf, which had been kept in a dry situation for the last thirty days, there appeared to be a much greater quantity of roots in the former; but owing to the number of stones, in both the one and the other, the earths themselves were not subjected to ultimate analysis.

The young plants were all cut down close by the earth on the 13th July, and dried, when their weight was 27·8 grains, and constituted of

| | | |
|---|---|---|
| Carbon | 40·1 | 11·15 |
| Hydrogen | 5·7 | 1·59 |
| Oxygen | 44·4 | 12·34 |
| Nitrogen | 4·2 | 1·17 |
| Ashes | 5·6 | 1·55 |
| | 100· | 27·8 |

This experiment also disposes us to infer, that carbon is made by plants. This sample of parched turf yielded; when plentifully supplied with water during vegetation gave—

| | | |
|---|---|---|
| Carbon imparted to the atmosphere in carbonic acid gas .. | 20·1 | grains |
| Do. in the plants ........ | 11·15 | „ |
| Do. in the roots ........ | 3·11 | „ |
| | 34·36 | |

And appeared to leave the earth as rich in vegetable matter as it was at the commencement.

These experiments afford strong evidence that carbon is a vegetable product made by plants; and enable us to account for many practical as well as chemical phenomena, which have presented themselves in the course of the inquiry. The subject will be more fully investigated in another part of the research. In the mean time we shall proceed to make further inquiry into the economy of plants, and the carbonic acid in the atmosphere.

## PLANTS IMPART TO THE AIR MORE CARBONIC ACID THAN THEY REMOVE FROM IT.

From the experiments recorded under the two last heads, it has appeared that plants during the performance of their regular functions, furnish to the atmosphere carbonic acid gas. Other experiments may be made which tend to prove that this gas is removed from the air during their luxuriant growth, forming two features in vegetable physiology apparently in direct opposition. But, as we have seen, that plants increase their own quantity of carbon, and, at the same time, add to the proportion of carbonic acid in the surrounding air, it is evident that if they remove carbon from the atmosphere, they also impart it to the atmosphere in a still greater degree.

In making experiments of this kind, there are many difficulties to contend with. One is, the tendency which plants have to decay, when placed under such circumstances as they must necessarily be kept. This decay must be especially guarded against, as every species of it has for one of its constant products carbonic acid gas; the formation of which vitiates the experiment.

Those plants, which are best calculated for furnishing us with information upon this subject, are so constituted, that the smallest injury to any of their parts, generally gives rise to a spontaneous change, foreign to that of vegetation, and which very soon passes into putrefaction. The slightest break in a freely grown leaf, will so favour this spontaneous change, which has for one of its products carbonic acid; that the quantity of this gas which is given off in consequence, very sensibly affects 100 cubic inches of atmospheric air. A similar effect is produced by the natural change from green to brown in the leaves of plants. The incidents which thus affect the constitution of a limited atmosphere, must produce similar changes in the ordinary atmosphere, and cause the production of carbonic acid. It is necessary, therefore, in proving by experiment, whether or no, plants impart more carbonic acid to the atmosphere than they take from it; that every part of the plant experimented upon, should be entirely free from blemish and decay, during the whole course of the experiment.

When we take into consideration that plants are constantly making carbon, and that carbonic acid is formed and given off to the atmosphere upon every change which takes place in plants, (independently of the carbon given off during the night and cloudy weather,) we find in broken stems and fading leaves, ample sources from which carbonic acid may be supplied to the atmosphere. The tendency to decay is, of course, greater when the plant is placed under circumstances unfavourable to vegetation, especially when its roots are removed from one medium of nourishment to another. The plant then generally exhibits a functional unhealthiness, whether the change be from earth to water, or from water to earth, or from one kind of water to another.

When cuttings or roots of plants are removed from the soil in which they have vegetated, and placed in distilled water only, the period of the healthy performance of their functions is confined, in many instances, to a few hours. But if, instead of distilled water, we use river or well water, which contains a little earthy matter not inimical to their growth, together with the ordinary quantity of carbonic acid found in these kinds of water, the plants will vegetate, and live for a much longer period.

The spring or early summer is the season most favourable to these experiments. Cuttings from healthy young plants may then be employed, to exhibit the phenomena connected with the carbon in plants and in the atmosphere.

My best experiments of this sort have been made with cuttings and roots of mint, prepared and conducted in the months of May and June. These were placed in river water, 1 lb. of which contained two-thirds of a grain of organic matter, two grains of earthy ingredients and salts, and about $\frac{1}{500}$ of its volume of carbonic acid. Two four-ounce bottles filled with this kind of water were placed on plates;

into each bottle was put a sprig of mint, without the roots. Each of these sprigs weighed 25 grains. The experiments were covered with glass shades, whose contents were 206 and 220 cubic inches, and stood where the sun shone from the rising until 3 P.M.; and had atmospheric communication cut off by water, lying about two-tenths of an inch in depth.

These two experiments never had their atmosphere changed, and were kept at a temperature, varying with the day and night in the months of May and June, from 60° to 80°. The plants wore a healthy appearance for seven days, had increased their number of leaves, from eight to twelve, and several roots had shot forth. On the eighth day, the experiments were terminated; the carbonic acid gas under the smaller shade had increased to 1·54 per cent., and that in the larger to 1·5 per cent.; making the carbonic acid imparted to the atmosphere by the plants—

| | |
|---|---|
| Under the smaller shade . | 3·09 cubic inches. |
| larger ditto . | 3·22 „ |

containing together ·82 of a grain of carbon.

On drying the two at 130°, their joint weight was 10·24 grains; and on being analyzed, yielded—

| | | |
|---|---|---|
| Carbon . . . | 41·73 . . | 4·27 |
| Hydrogen . . . | 5·16 . . | ·53 |
| Oxygen . . . | 40·77 . . | 4·18 |
| Nitrogen . . . | 2·34 . . | ·24 |
| Ashes . . . | 10·00 . . | 1·02 |
| | 100 | 10·24 |

Two of the sprigs of mint, similar to these which were put under experiment, were dried at the same temperature. These weighed 7·08 grains, and were constituted of—

| | | |
|---|---|---|
| Carbon . . . | 41·74 . . | 2·96 |
| Hydrogen . . . | 5·19 . . | ·37 |
| Oxygen . . . | 38·76 . . | 2·74 |
| Nitrogen . . . | 2·31 . . | ·16 |
| Ashes . . . | 12·00 . . | ·85 |
| | 100 . . | 7·08 |

Giving results, on comparing the plants—

| | Carbon. | Hydro. | Oxygen. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| After 8 days' vegetation | 4·27 | ·53 | 4·18 | ·24 | 1·02 | 10·24 |
| Before vegetation .... | 2·96 | ·37 | 2·74 | ·16 | ·85 | 7·08 |
| Difference .... | 1·31 | ·16 | 1·44 | ·08 | ·17 | 3·16 |

an increase of carbon equivalent to 44·2 per cent.; and on including the carbon in the carbonic acid given off by the plants, the increase of that body is equal to 77·3 per cent.

Two other experiments were made with similar sprigs of mint, kept in the open air. During the period of the eight days there was not an appreciable difference in their external characters. They weighed, when dried at the same temperature, 10·6 grains, and were constituted of—

| | | |
|---|---|---|
| Carbon . . . | 41·94 . . | 4·45 |
| Hydrogen . . . | 5·18 . . | ·55 |
| Oxygen . . . | 40·62 . . | 4·30 |
| Nitrogen . . . | 2·06 . . | ·22 |
| Ashes . . . | 10·20 . . | 1·08 |
| | 100 . . | 10·6 |

Two other experiments were made with roots of mint, each weighing 22 grains, and containing 14 leaves. These stood under glass shades for 28 days. The atmosphere was changed six times. One of the experiments gave 6·6, and the other 7·2 cubic inches of carbonic acid. Although these plants, during the period of their growth, increased their number of leaves and roots as much as those which grew in the open air; yet the roots and leaves were much smaller. At each examination every part of the plants which had the slightest appearance of decay was removed. The carbonic acid above mentioned, may therefore be regarded as proceeding from the plants when they were in a healthy, but not in a vigorous state of growth. Their weight, when dried at 120°, was 12·2 grains, comprised of—

| | | |
|---|---|---|
| Carbon | 41·0 | 5·00 |
| Hydrogen | 6·0 | ·73 |
| Oxygen | 42·7 | 5·21 |
| Nitrogen | 1·9 | ·23 |
| Ashes | 8·4 | 1·03 |
| | 100 | 12·2 |

These gave, when compared with the original constitution of the plants—

| | Carbon. | Hydro. | Oxygen. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| After vegetating 28 days | 5·00 | ·73 | 5·21 | ·23 | 1·03 | 12·2 |
| Before vegetation .... | 2·92 | ·36 | 2·69 | ·13 | ·86 | 6·96 |
| Difference .... | 2·08 | ·37 | 2·52 | ·10 | ·17 | 5·24 |

an increase of 71·2 per cent. of carbon, independently of that in the carbonic acid imparted to the atmosphere, which would make the quantity of carbon in, and made by the plants 6·8 grains; more than twice the quantity contained in the plants at the commencement.

Those experiments, which stood by the side of the preceding, in the open air, remained in the bottles six days longer. They, when dry, weighed 22·9 grains, and were constituted of—

| | | |
|---|---|---|
| Carbon | 41·0 | 9·37 |
| Hydrogen | 5·3 | 1·21 |
| Oxygen | 42·2 | 9·66 |
| Nitrogen | 2·0 | ·46 |
| Ashes | 9·5 | 2·20 |
| | 100 | 22·9 |

These experiments confirm the proposition that carbon is a vegetable product. They also shew that the plants, at the same time that they make carbon, impart more carbonic acid to the atmosphere than they remove from it. The carbon made, does not bear an exact proportion to that which is found added to the atmosphere. This is especially the case when the air in the various experiments is examined at different intervals. In the above experiments, when the atmosphere remained unchanged during the period of making 44·2 per cent. of carbon, there was found added to the atmosphere 27·7½ per cent. When the atmosphere was changed every fourth day during the period of making 71·2 per cent. of carbon, 70·5 per cent. was found to have been added to the atmosphere. These differences dispose us to infer that there is either a want of uniformity in the operations of plants, or, what is more probable, as we shall presently see, a part of this gas must disappear by some other process.

We also learn from these experiments, that the mint plant will vegetate in limited atmosphere for several days; but it does not increase so much in carbon as when it grows in the open air; a circumstance, which could not proceed from the want of carbon in the atmosphere, because in the experiment in which most carbon was present in the air, there was least found in the plants.

The general results of my experiments, lead me to suppose that the carbonic acid which is given off to the atmosphere by any plant, bears a nearer proportion to the increased quantity of carbon, than to the original weight of carbon in the plant.

### PLANTS DO NOT INCREASE THEIR QUANTITY OF CARBON WHEN CARBONIC ACID IS REMOVED FROM THE ATMOSPHERE IN WHICH THEY GROW.

That some plants in their growth make a portion of that carbon which is found in their constitution, is evidenced in the experiments described under the two last heads. It also appears, from the same experiments, that during the period of their making this carbon, they are imparting to the atmosphere the same body in combination with oxygen, forming carbonic acid gas.

Now, as plants at the same time increase their own carbon, and give it off to the surrounding air, one might suppose this body to be a superfluous part of the atmosphere—so far as the requirements of plants are concerned; and that they would perform all their functions with as much regularity, energy, and force, if the carbon were entirely removed from the air in which they vegetate. But this is not the case; for although the carbonic acid does not appear to us, to do much towards furnishing carbon to plants, its importance as an agent in vegetable economy, is very apparent, when we either remove it entirely, or even partially from the atmosphere. None of my experiments have yet satisfactorily proved, that plants make carbon when the carbonic acid is removed from the atmosphere. The experiments which went nearest to prove it, were made with small but healthy roots of mint, taken from a wet soil in a shaded situation. These were placed in cold water for twenty-four hours. Two of these roots, resembling each other in every respect, were selected; on each there were fourteen small leaves. Each sprig was 14·5 grains in weight. Four similar roots were immediately dried at a temperature not exceeding 120°, when they weighed 8·8 grains, and were constituted of

| | | |
|---|---|---|
| Carbon | 41·0 | 3·60 |
| Hydrogen | 5·1 | ·44 |
| Oxygen | 40·2 | 3·56 |
| Nitrogen | 2·4 | ·20 |
| Ashes | 11·3 | 1·00 |
| | 100 | 8·8 |

Those sprigs of mint which formed the vegetative experiment, were separately put into narrow three-ounce bottles, two-thirds filled with the river water, mentioned page 76.

These bottles were placed in tubes of twice their internal diameter; at the bottom of each was 100 grains of quick lime, mixed with 500 grains of water. The tubes were placed on plates filled with water, and covered with glass shades whose contents were 75 and 98 cubic inches.

The experiments were fitted up on the 29th of May, and continued until the 22nd of June. The shades were removed every second day; fresh atmospheric air supplied; and the thin crust of carbonate of lime which covered the water, dispersed. The progress and condition of the two plants were very similar.

On the second day the two bottom leaves fell off; on the fourth day every leaf was much shrivelled up, and the two lower leaves were drooping. At this time two fresh leaves sprouted out at the top. The lower leaves now began to drop off, one after another; and on one of the plants, at the places where the leaves dropped off, small buds appeared, which on the tenth day became small stems, with very small leaves. On the fifteenth day, two other small buds made their appearance where the second leaves from the bottom had grown; and on the twentieth day two others were set. The number of leaves, including the eight which had fallen off, increased from fourteen to twenty-two. From the twentieth day the plants appeared to make very little progress in growth. On the twenty-fourth day the leaves which had fallen off, the roots which had increased in number and length, together with the two entire plants, were dried, and when subjected to analysis, weighed 5·5 grains, and were constituted of—

| | | |
|---|---|---|
| Carbon | 40.8 | 2·24 |
| Hydrogen | 5·0 | ·28 |
| Oxygen | 40·6 | 2·23 |
| Nitrogen | 2·6 | ·14 |
| Ashes | 11·0 | ·61 |
| | 100 | 5·5 |

On a recapitulation, we have,

| | Carbon. | Hydro. | Oxygen. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| At the conclusion .... | 2·24 | ·28 | 2·23 | ·14 | ·61 | 5·5 |
| At the commencement | 1·80 | ·22 | 1·78 | ·10 | ·50 | 4·4 |
| Difference .... | ·44 | ·06 | ·45 | ·04 | ·11 | 1·1 |

shewing an increase of 24·4 per cent. of carbon, the whole of which may be regarded as having been made by the plants, living in an atmosphere containing very little carbonic acid; for in these, as well as every other experiment mentioned under the different heads, the water which was employed, always contained more organic matter at the conclusion, than at the commencement of the experiments. It is worthy of remark, that the water left in those experiments contained much less organic matter, than that left by those plants which were kept under shades without being surrounded by lime — or by those which had been fully exposed to the surrounding atmosphere. This was evidenced in the following experiments, made at the same time, and with similar roots of mint.

These stood by the side of the other experiments, and were fully exposed to the atmosphere, and to the sun's rays, six hours in the day. The leaves on each likewise increased from fourteen to twenty-two, the same as the others; but they remained on the stems, increased in size, and were in a healthy condition until the final examination. Their roots had also increased in number and length; some of them when stretched out, measured eight inches. The whole on being dried and analyzed, showed an increase of carbon equal to 151, and of nitrogen 186 per cent., without taking into account the organic matter in the water, which was very considerable in quantity, beyond that in the experiment in which lime was employed.

Another stem of mint, in a bottle of water surrounded by lime-water, covered with a glass shade, and kept under an increase of 15° of temperature, shed all its leaves, the stem withered from the top to the surface of the water, and four small stems made their appearance on the part under the water. On these were four, six, and eight small leaves, all of which were healthy, until the seventeenth day, when the experiment was dried, and by analysis found to have lost 5·8 per cent. of carbon.

Four experiments were made with only half the quantity of water to each portion of lime; and the surface of the water and lime was twice that of the others. They were all placed under one glass shade, whose content was 400 cubic inches, and whose height was only one-half of that of the other shades. Roots of mint, in bottles of water, were placed in the lime water, under the shades, as before. Two were supplied with river water, and two with very clean rain water (which is less favorable to the growth of plants of this kind than river water, but more favorable than fresh distilled water). The atmosphere was changed every four days.

After the first four days, all these plants began to show signs of inactive vegetation: the leaves, although retaining their color, began to droop, and fell off one after another. On the sixteenth there were only two of the eight leaves left on each stem.

On collecting the leaves and stems, drying them and subjecting each experiment to analysis, they were found to have lost carbon, after the following rate, viz:—

| | | | |
|---|---|---|---|
| In rain water | No. 1 | 16·7 | per cent loss. |
| | No. 2 | 17·6 | „ |
| In river water | No. 3 | 18·9 | „ |
| | No. 4 | 24·0 | „ |

The experiments which were kept under similar circumstances, the lime water excepted, increased their quantity of carbon. These gave—

| | | |
|---|---|---|
| In rain water | 7·4 | per cent. increase. |
| In river water | 11·8 | „ |

A variety of other experiments give results which lead to the conclusion, that some plants will live and increase their quantity of carbon with a very small proportion of carbonic acid in the atmosphere. But I have no experiments which conclusively prove that plants make carbon, or even grow, without any carbonic acid in the atmosphere which surrounds them.

The first experiment detailed under this head, goes furthest towards proving this; yet it is not satisfactory; for on admitting fresh atmospheric air occasionally, the plants were in a situation where they might benefit by the influence of the carbonic acid which it contained. Besides, we are not certain that the atmosphere in which these plants grew, had its carbonic acid entirely removed; and further, there was carbonic acid in the water in which these plants were kept.

The germination of seeds, and growth of seedling plants, favor the supposition that vegetation can take place independently of the carbonic acid properly belonging to the atmosphere. If we place seeds, which have absorbed as much moisture as will favor their growing, in an atmosphere deprived of its carbonic acid, they germinate; and the plants (if in contact with the carbonic acid, given off by the seeds,) continue healthy, and grow nearly as luxuriantly as if they were in the open air.

In experiments of this kind, the carbonic acid which is given off by the seeds, until removed by lime or caustic alkalies, comes in contact with the plants, and may perform its part as an agent in vegetation.

When experiments, which have been kept in an atmosphere from whence the carbonic acid has been removed, are placed either in the open air, or within glass shades containing atmospheric air, to which from two to five per cent. of carbonic acid has been added, they generally grow very luxuriantly.

The subject requires to be more fully investigated before we can come to any decided conclusion. But it is probable, that carbonic acid is a part of the atmosphere essential to the growth of plants; that a portion of the carbon which is found as increase in plants, proceeds from the atmosphere; and consequently, that plants cannot make carbon in an atmosphere destitute of carbonic acid.

### INFLUENCE OF CARBONIC ACID IN THE ATMOSPHERE UPON THE GROWTH OF PLANTS.

That the carbonic acid of the atmosphere exerts an influence on the growth of plants, is apparent from the preceding experiments. Not only do we find that by removing a portion of this gas from the atmosphere, their growth is sensibly retarded, but if we introduce sickly plants into an atmosphere somewhat surcharged with carbonic acid, and place them in the sun's rays, a portion of the carbonic acid soon disappears, oxygen gas is given off, the plants appear to have acquired new energies, the drooping leaves are raised, and even expanded, and the plants in a few hours are increased in size.

These results are so apparent, as to lead vegetable physiologists to infer, that the plants have appropriated a portion of the carbon in the acid to their own purposes.

It must be observed, that if the plants have been previously kept in a confined atmosphere, which contains more carbonic acid than is found in the common air, they rarely derive any benefit from being introduced to an atmosphere, which contains a still larger proportion of carbonic acid. If, for example, plants be kept in a confined atmosphere until the proportion of carbonic acid is increased to more than from five to eight per cent. on being introduced into one which contains fourteen per cent. of this gas, the presence of so large a quantity, rather hastens their decay than promotes their growth.

In making experiments on the influence of carbonic acid on the growth of plants, we notice that one plant will live and thrive in an atmosphere containing ten, twelve, or fourteen per cent. of its volume of carbonic acid; and another will not grow at all in such a mixture, but rather passes into decay. Peas removed from the common atmosphere, and placed in one containing ten per cent. of carbonic acid, will grow freely for several days; but if we make the experiment with wheat or barley, they very seldom grow, but generally languish and die in four or five days.

We are indebted to De Saussure* for a course of experiments which furnish us with information as

* Recherches, p. 27.

to the influence of carbonic acid gas upon the growth of plants. He made his experiments with peas which had germinated in distilled water. The roots of some were placed in contact with pure distilled water, and others in contact with the same kind of water holding in solution one-fourth of its volume of carbonic acid. The plants in contact with the acidulated water were, at the end of a month, more fully developed, and had increased in weight more than those which had grown in pure distilled water.

Saussure made other experiments with peas which had germinated in water until each plant was four inches high, and weighed 20 grains. He then placed three for each experiment, in a glass filled with water, in such a manner that the roots alone were in the liquid. These were kept under receivers containing different mixtures of common air and carbonic acid gas: atmospheric communication was cut off by water covered with oil.

The experiments were exposed for six hours each day to the sun's rays. In ten days, those kept in pure atmospheric air had increased about 8 grains; those in an atmosphere containing one-twelfth of its volume of carbonic acid increased 11 grains; in one-eighth, the increase in weight was 7 grains; in one-fourth, the increase was only 5 grains. When the carbonic acid formed one half the volume, they faded in seven days; and upon increasing the volume of carbonic acid to two-thirds and three-fourths, and when placed in pure carbonic acid, they faded immediately upon being exposed to the sun's rays.

He repeated these experiments several times, and found that plants generally grow better, in an atmosphere containing one-twelfth its volume of carbonic acid, than in pure atmospheric air. Those which grew in the latter, neither changed the volume nor the purity of the atmosphere; but those in the artificial mixture, changed nearly all the carbonic acid into oxygen gas.

When the experiments were kept in the shade, the results were the reverse of these. When in pure atmospheric air for ten days, their increase was five grains; when in an atmosphere containing one-twelfth of carbonic acid, they increased only three grains; and when the proportion of the acid gas was raised to one-fourth, they died in sixteen days.

Saussure made another experiment upon the influence of carbonic acid on the growth of plants when exposed to the sun; which proves in a direct manner that earth is useful to vegetation, not only by furnishing food to the roots, but also by the influence it has upon the atmosphere.

He suspended in the upper part of a receiver, which contained 150 cubic inches of atmospheric air, two ounces of moist earth. Within this receiver he placed peas partly developed, their roots being in pure water. The external atmosphere was cut off by means of water. At the end of ten days those plants within the receiver containing the earth, increased more than similar plants under a receiver where no earth was present. These experiments of De Saussure's would have been much more conclusive, with regard to the influence of carbonic acid upon the growth of plants, if either their dry weight, or ultimate analysis had been accurately determined before and after experiment.

My experiments upon this subject were made with wheat, peas, and turnip plants. The results were not very satisfactory, probably owing to the want of sunshine. They all increased in weight, and generally the increase was greater in those which had been supplied with carbonic acid; but the difference was too trifling to warrant a conclusion without other evidence. Experiments made with cuttings of plants are perhaps better calculated for testing the hypothesis, that the growth of plants is favoured by the introduction of carbonic acid. These will be detailed in the next section, where it is attempted to shew that the

### INCREASE OF CARBON IN PLANTS IS NOT EQUAL TO THAT WHICH DISAPPEARS FROM THE ATMOSPHERE.

When plants grow in an atmosphere surcharged with carbonic acid, they increase their carbon; and the quantity of carbonic acid which is removed from the atmosphere is greater than in ordinary cases. Hence we may infer; either, that the carbon which is removed from the atmosphere is absorbed by the plant; or, that the carbonic acid which is removed is only to a certain degree absorbed by the plant, and that the rest disappears by some process unknown to us; or, at the same time that the carbonic acid disappears by this unknown process, carbon is made by the plant. On the first supposition, the increased quantity of carbon in the plant, will be the measure of that which has disappeared from the atmosphere; on the other supposition, it would not.

| FIRST. | | Grains. |
|---|---|---|
| Original weight of carbon in plant . | . | 10 |
| „ „ „ | atmosphere | 10 |
| | | —20 |
| After vegetation | In plant . . . | 15 |
| | In atmosphere . . | 5 |
| | | —20 |

Shewing neither gain nor loss of carbon.

### SECONDLY.

| | | Grains. |
|---|---|---|
| Original weight of carbon in plant and atmosphere | | 20 |
| After vegetation | In plant | 10 |
| | Assimilated by do. | 3 |
| | In atmosphere | 5 |
| | | 18 |
| Loss of carbon | | 2 |

### THIRDLY.

| | | |
|---|---|---|
| Original weight of carbon in plant and atmosphere | | 20 |
| After vegetation | In plant | 10 |
| | Made by do. | 3 |
| | In atmosphere | 5 |
| | | 18 |
| Loss of carbon | | 2 |

In this case five grains would be destroyed, and three new grains made.

I am not aware that any experiment has been made that will support the first of these suppositions. That one or the other of the two latter is correct, may be drawn, as well from the labours of different experimenters, as from the varied experiments I have made upon this subject.

Dr. Daubeny, in his experimental investigation into the evolution of oxygen during the growth of plants found that "the disappearance of carbonic acid always more than kept pace with the addition to the quantity of oxygen; but the shortness of the time during which the plants could be retained in a sufficiently healthy condition prevented his ascertaining whether, after the carbonic acid had been absorbed, a part was not at some subsequent period given out again unchanged."

In one experiment, the geranium, " during a bright sun, absorbed 9·5 per cent. of carbon and emitted 5 per cent. of oxygen." In another experiment with the young lilac, "the remarkable clearness of the sky, and the warmth of the weather during three days was peculiarly favourable to the experiment. Increase of oxygen 8·5 per cent. The quantity of carbonic acid which disappeared did not so much exceed that of the oxygen given out in the experiment on the geranium."*

If the disappearance of carbonic acid in all these experiments, more than kept pace with the addition to the quantity of oxygen to the atmosphere, what became of the difference of gaseous volumes? As no change in volume results from the separation of carbon from the carbonic acid, there would, in the experiment with the geranium, have been a deficiency of, from 24 to 30 cubic inches. We have no experimental evidence which would warrant the conclusion that it underwent decomposition; its carbon and oxygen combining with, and forming part of the plant. The most probable conclusion is, that it comes under either the second or third example above cited; a view supported by the experiments made by De Saussure with a view to solve Priestley's discovery of the decomposition of carbonic acid by plants.†

He introduced into a jar, whose content was 350 cubic inches, so much carbonic acid as made the proportion when tested by lime water 7½ per cent. This jar covered seven periwinkles (*vinca minor*), whose height was eight inches, and whose roots were in a vessel, containing a portion of water incapable of abstracting an appreciable quantity of the carbonic acid.

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* Philosophical Transactions, 1836.

† Saussure's Researches, p. 40.

Atmospheric communication was cut off by mercury, upon the surface of which was a little water. The experiment was kept, with little variation, at 70° of temperature, and exposed to the sun's rays six hours in the day.

On the seventh day the atmosphere, after making all corrections, had undergone little, if any change in volume. No carbonic acid could be detected in the atmosphere by lime water; but it contained 24·5 per cent. of its volume of oxygen.

On comparing the weight of charcoal obtained by carbonization, from the periwinkles which had been put under experiment; with that obtained from those which had not; the increased weight of charcoal resulting from the former, only contained about half the carbon which had disappeared from the atmosphere.

This experiment is in favour of the second or third supposition. Had the experiments shewn that the increase of carbon in the plants was exactly equivalent to that which disappeared from the atmosphere, it would have supported the theories propounded by Professor Liebig, who, in allusion to the experiments of M. de Saussure, and speaking of the decomposition of carbonic acid by plants, says, "The atmosphere must thus receive a volume of oxygen for every volume of carbonic acid which has been decomposed. This remarkable property of plants has been demonstrated in the most certain manner, and it is in the power of every person to convince himself of its existence. The leaves and other green parts of a plant absorb carbonic acid, and emit an equal volume of oxygen."*

My experiments on this subject were made in May and June with sprigs of mint, weighing 22 grains each. Two were immediately dried at a temperature not exceeding 130° Fahr., afterwards exposed to the atmosphere for twenty-four hours, when their united weight was 6·96 grains, and constituted of

| | | |
|---|---|---|
| Carbon | 41·94 | 2·92 |
| Hydrogen | 5·16 | ·36 |
| Oxygen | 38·62 | 2·69 |
| Nitrogen | 1·88 | ·13 |
| Ashes | 12·40 | ·86 |
| | 100· | 6·96 |

Other two sprigs were made the subject of separate experiments conducted in the following manner: each sprig was put into a three-ounce bottle, two-thirds filled with river water, placed on a plate by the side of another bottle, containing five cubic inches of carbonic acid, and immediately covered with a glass shade. The content of one shade was 200, and of the other 206 cubic inches. Atmospheric communication was cut off by mercury, and a thin covering of water. The experiments were exposed to the sun's rays from its rising till 3 P. M.

The atmosphere was examined at 1 P. M. on the second, fourth, sixth, and eighth day, by uncovering the experiments, and analyzing the air in the gas bottles. On the second, fourth, and sixth day, five cubic inches of carbonic acid was supplied: thus, the plants which formed each experiment were in eight days supplied with 1640 cubic inches of fresh air, including 20 cubic inches of carbonic acid gas.

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* Liebig's Agriculture, page 19.

Of the great number of experiments that were made in May and June, these under description were the only ones favoured with fine weather during the entire eight days,—the sun shining brightly on each day.

In one of the experiments there disappeared 15·2, and in the other 15·6 cubic inches of carbonic acid, containing together 4·03 grains of carbon.

On the seventh day the plants wore a sickly appearance; several of their leaves had faded and fallen off.

On the eighth day they were removed from the water, and immediately dried at a temperature not exceeding 130°, and afterwards exposed for twenty-four hours.

The water on being tested did not appear to contain more carbonic acid than that in which other plants of a similar kind had grown, and to which no carbonic acid had been added; neither did it contain an appreciable increase of organic matter. The water which covered the mercury was nearly all dried up on the eighth day. The sprigs, including the roots, stems, and leaves, weighed when dry 5·4 and 5·2 grains respectively. On being powdered together and analyzed, the whole was constituted of

| | | |
|---|---|---|
| Carbon | 42·01 | 4·45 |
| Hydrogen | 5·15 | ·55 |
| Oxygen | 39·75 | 4·21 |
| Nitrogen | 1·81 | ·19 |
| Ashes | 11·28 | 1·20 |
| | 100· | 10·6 |

These give, on recapitulation—

| | Carbon. | Hyd. | Oxygen | Nitr. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| Original constitution .... | 2·92 | ·36 | 2·69 | ·13 | ·86 | 6·96 |
| Carbonic acid disappeared | 4·03 | | | | | |
| Total .......... | 6·95 | ·36 | 2·69 | ·13 | ·86 | 6·96 |
| After eight days growth .. | 4·45 | ·55 | 4·21 | ·19 | 1·20 | 10·6 |
| Increase ........ | .. | .. | .. | ·06 | ·34 | 3·64 |
| Decrease ........ | 2·50 | .. | .. | .. | .. | .. |

Hence the carbon in the plants increased 1·53 grains, equivalent to 53 per cent., at an expense of 4·03 grains, equal to 138 per cent., losing 38 per cent., and a loss of 2·5 grains of carbon in the experiment, equivalent to 30 per cent. in eight days; every one of which was favourable for the decomposition of carbonic acid by plants.

These experiments, like those of Dr. Daubeny and M. de Saussure, teach us that the amount of carbon which disappears from the atmosphere, is not a correct measure of that which is taken up by the plants; but how, and in what manner this carbon is lost, is not explained by any of the experiments.

The results of the next experiments to be described, do not much tend to explain in what manner the carbonic acid disappears; but they indirectly show, that its disappearance is an effect produced by plants, in a few hours of bright sunshine.

These were made with sprigs of mint, and conducted under circumstances similar to the last; with this exception, that in those already described, the air was examined at 1 P. M., whilst in these, it was removed in the morning before the sun's rays had affected the carbonic acid in the atmosphere and the plants. There was an increase of carbonic acid in one of these experiments equal to 5·2, and in the other 4·6 cubic inches. The weight of the two plants, when dried, mixed, and powdered, was 9·3 grains, and constituted of

| | | |
|---|---|---|
| Carbon | 42·2 | 3·92 |
| Hydrogen | 5·2 | ·48 |
| Oxygen | 40·6 | 3·78 |
| Nitrogen | 1·9 | ·18 |
| Ashes | 10·1 | ·94 |
| | 100· | 9·3 |

Giving, on a recapitulation of the products—

Carbon in the plants in the eighth day 3·92 grs.
Do. in the excess of carbonic acid . . 1·28 „

Total . . . . . . . . . . . . 5·2
Do. originally in plants . . . . . . . . . . 2·92

Do. in increase . . . . . . . . 2·28

In these experiments the carbon in the plants increased one grain, equivalent to 44 per cent.; that in the carbonic acid 1·28 grains, equal to 25 per cent.; shewing an increase of carbon in the experiment of 2·28 grains, equal to 28 per cent. When we compare these results with those obtained from the other experiments on mint, we are led to infer; that the disappearance of carbon from the atmosphere in which plants vegetate, is intimately connected with the operation of the sun's rays.

We have here two sets of experiments upon the mint plant, conducted alike in every respect, with one exception, viz., the time of changing the atmosphere in which they grew. These experiments give results differing very widely. In the first set we have a loss of carbon; and in the second, a gain of this body. In the first, where there is a loss of carbon, 30·8 cubic inches of carbonic acid has disappeared. In the second, in which carbon was made, there was an increase of 9·8 cubic inches in the volume of this gas; making a difference of 40·6 cubic inches of carbonic acid, comprising 5·2 grains of carbon. In the first, where there is a loss of carbon sustained in the experiment, the carbon in the plants was increased from 2·92 grains to 4·45 grains. In the second, where there is an increase of carbon in the experiments, the carbon in the plants was increased from 2·92 grains to 3·92 grains, making a difference in the weight of the carbon assimilated by the plants of ·53 of a grain. To what are we to ascribe these differences?

The following statement, shews the difference in the quantities of carbonic acid obtained from the atmosphere, in experiments examined at different intervals, but otherwise similarly conducted:—

| | | |
|---|---|---|
| In the morning before sunrise | The quantity may be represented when the experiments are examined every day by | 1,000 volumes |
| | 2nd day by | 900 |
| | 3rd day by | 820 |
| | 4th day by | 750 |
| | 5th day by | 690 |
| | 6th day by | 640 |
| | 8th day by | 580 |
| | 10th day by | 540 |

| | | |
|---|---|---|
| In the afternoon, after bright sunshine .... | When examined every day by from | 5 to 12 |
| | .............. 2nd day by .. | 7 .. 15 |
| | .............. 3rd day by .. | 10 .. 22 |
| | .............. 4th day by .. | 14 .. 30 |
| | .............. 5th day by .. | 19 .. 40 |
| | .............. 6th day by .. | 25 .. 50 |
| | .............. 10th day by .. | 35 .. 60 |

In the experiment with mint, (page 61,) when the examination was made every fifth or sixth day, the carbon in the carbonic acid given off by the plant, was nearly two-thirds the increased weight of this body in the plant; and in the experiment with the seedling wheat plants, (page 63,) the carbon in the acid was equal to that in the developed plant, the examinations being made at intervals of six and seven days. Now, if we make allowance for the difference between the quantity of carbon obtained when the air was examined every sixth day, and every day, and consider these experiments as representing what takes place in the ordinary course of vegetation, we shall find the weight of carbon in the carbonic acid given off by plants 117 per cent. of the weight of that in the vegetables which cover the earth. And if we calculate for the disappearance of this gas, according to the above ratio of carbon in the carbonic acid, when the air is examined in the afternoon, we only find from 1 to 10 per cent.[§] of this weight of carbon in the atmosphere. What then has become of the $\frac{9}{10}$? Or if we take what is proved by experiment upon the turf clothed with grass, (page 68,) as representing what takes place in vegetation generally, we have the carbon in the carbonic acid, when the atmosphere was changed in the morning, seven times that in the plants produced. Had the atmosphere of the experiment been examined in the evening, we should have found that $\frac{6}{7}$ at least of this acid had disappeared, without the plants increasing much in carbon. What then, in this case also, becomes of the $\frac{6}{7}$ths? We find that it has disappeared from the atmosphere, but none of our experiments shew that it has entered into the constitution of the living vegetables. Saussure's experiments already mentioned, (pages 52-58,) as well as common experience, teach us, that when we have the most carbon in the atmosphere, we have also the greatest quantity of this body in the vegetables which cover the earth.

In Dr. Daubeny's results; the carbonic acid which disappeared always exceeded that of the oxygen which was given off, showing a loss in the volume of this gas. In M. de Saussure's experiments the carbon assimilated by the plants was only 56 per cent. of that which disappeared. In my first described experiments on the mint plant, when the constitution of the atmosphere was examined at 1 P.M., the increased weight of carbon in the plants was equivalent to 62 per cent. of that in the carbonic acid which disappeared. My experiments on the mint plant, which were examined early in the morning, would dispose us to infer, that these losses of carbon, form only a part of that loss which is really sustained in experiments of this kind. Every experiment leads to the conclusion; that plants make carbon, and that the carbon assimilated by plants, is not equal to that in the carbonic acid which disappears from the atmosphere.

## WHAT BECOMES OF THE CARBONIC ACID WHICH DISAPPEARS FROM THE ATMOSPHERE DURING THE GROWTH OF PLANTS.

On examining experiments upon the growth of a variety of plants several years ago, I had occasion to notice that carbonic acid was a constant product, emanating as well from the roots of plants, as from their leaves and stems.

Bearing in mind what has been already shown by experiment, as to the disappearance and evolution of carbonic acid during the growth of plants, I would here observe, that in whatever manner I have made the experiments, when the atmosphere contained a less proportion than one per cent. of this gas, it was never all removed, but the proportion, in almost all cases, was increased.

Experiments were made in the month of June with healthy plants of different kinds, on which there appeared no signs of decay, and which had vegetated under glass shades; atmospheric communication being cut off by water. These glass shades were removed on the mornings of bright sunshine between the hours of 10 and 12 A.M., filled with atmospheric air, and replaced. The experiments were kept under the direct influence of the sun's rays from 4 A.M. to 6 P.M., when a portion of lime water was introduced. In less than half an hour, the water was always covered with a thin film of carbonate of lime, showing the presence of carbonic acid in the atmosphere. From these experiments I inferred, that when the quantity of carbonic acid in the air is reduced below the average proportion in the common atmosphere, no carbonic acid is removed from it by plants.

My next experiments were made to discover if that portion of carbonic acid gas which is given off by the roots of plants, combines with the water in the earth which surrounds them. This is undoubtedly the case if the roots are immersed in, or immediately in contact with water; for it then combines with the water, which at ordinary temperatures will hold its own volume of carbonic acid in solution. But upon passing an atmosphere comprising five per cent. of carbonic acid through 100 feet of water, at 60° of temperature, a portion of this gas, varying from ·8 to 1·0 per cent., was not removed by the water.

From these results I drew the inference, that when the roots of plants are surrounded by earth pervious to air, and slightly moistened with water, a portion only of the carbonic acid which is given off by the roots, will be taken up by this water, and the rest will mix with the intersticial air.

Having recently proved, that cuttings and roots of plants which vegetated in water always gave off carbonic acid gas; and having learned from the experiments just described, that a portion of it only would be taken up by the water which rendered the earth fertile; I expected that the remaining portion, which is given off in the ordinary course of vegetation, might be detected near the surface of the earth, in clumps of plants, when under vigorous growth. But my expectations were not realized; for upon examining experiments made upon air collected at different times of the day, in the months of June, July, and August, from the surface of the earth, covered with clumps of plants about two feet high, and growing so thickly upon the ground that the stems nearly touched each other, I found that the quantity of acid gas obtained from these samples of air, rarely contained more than was found in the surrounding atmosphere.

I then commenced a course of experiments to discover, whether this gas entered into chemical, or other combination with the soil.

Plain retorts, whose beaks were graduated into cubic inches, were filled with carbonic acid and atmospheric air; the former comprising from one to two-thirds of the whole volume. One-fourth of each of these retorts was filled,—some with calcareous mould, others with aluminous mould, and the remainder with silicious mould. Duplicates of the moulds were kept in corked bottles. Into other retorts, containing a similar atmosphere, were put various salts, fermented liquors, spirits of different kinds, acids, and into some water only.

The beaks of these retorts were first placed in mercury; a portion of water, about two-tenths of an inch in depth, was then introduced, and lay between the mercury and the atmosphere in each experiment. These retorts stood in this situation for several days, during which time, the rising of the mercury in some of the beaks more than in others, led me to suppose, that the difference of soil, had something to do with the different proportions of the carbonic acid which disappeared.

In consequence of the great quantity of mercury required for conducting experiments in so many retorts, I substituted water kept saturated with carbonic acid.

In the same vessel containing the saturated solution of carbonic acid in water, were arranged the beaks of from ten to fifteen of these retorts. When the saturated water rose in each retort, its volume in cubic inches was registered, and fresh carbonic acid introduced, without removing the beak of the retort from the water.

Some of these experiments were kept, and regularly attended to, for six months, and others for eighteen months. The following is a registered account of one of these experiments, which, along with ten others, had the beaks of the retorts in the same saturated water.

1 lb. of garden mould was put into a pint and a half retort, whose atmosphere was constituted of about 70 per cent. of carbonic acid and 30 of atmospheric air, and placed with its beak in water kept saturated with carbonic acid.

| Date.—1837. | | Time. | Loss of gas. Cub. inc. | Remarks. |
|---|---|---|---|---|
| April | 11 | Fitted up the experiment. | | |
| „ | 16 | | 0·5 | |
| „ | 17 | 8 A.M. | 4·0 | |
| „ | „ | 3 P.M. | 4·2 | |
| „ | 19 | „ | 3·5 | |
| „ | 25 | 10 P.M. | 15·5 | Principally in the last 24 hours. |
| May | 6 | „ | 4·2 | |
| „ | 10 | „ | 3·6 | |
| „ | 15 | „ | 7·5 | |
| „ | 18 | „ | 14·0 | Cloudy weather. |
| „ | 20 | „ | 14·5 | |
| „ | 21 | „ | 16·0 | |
| „ | 22 | „ | 15·0 | |
| „ | 23 | „ | 4·0 | |
| June | 7 | „ | 4·5 | |
| „ | 10 | „ | 10·8 | |
| „ | 19 | „ | 8·5 | |
| „ | 23 | „ | 4·0 | |
| „ | 26 | „ | 4·0 | |
| July | 17 | „ | 5·5 | |
| „ | 20 | „ | 10·0 | All in 24 hours. Cloudy weather. |
| „ | 31 | „ | 6·6 | |
| Aug. | 5 | „ | 12·0 | All in two days. |
| „ | 23 | „ | 4·0 | |
| Sept. | 2 | „ | 4·0 | |
| „ | 4 | „ | 15·8 | |
| „ | 6 | „ | 8·0 | |
| „ | 14 | „ | 10·0 | |
| „ | 27 | „ | 9·0 | |
| Oct. | 7 | „ | 3·5 | |
| „ | 14 | „ | 9·5 | |
| „ | 21 | „ | 16·0 | |
| „ | 23 | „ | 10·0 | |
| „ | 25 | „ | 12·0 | |

It is for future experiment to determine, how much of this gas was removed by the saturated water; how much by the water which was in contact with the soils, &c.; and how much by the organic and inorganic matter which constituted the mould. During the continuance of these experiments, I had occasion to make the following general observations.

First, during cloudy weather, when plants increase so much in size, and when they give off carbonic acid in large proportions, the volume of this gas in the atmosphere of the experiments generally, and especially in those containing the mould and water, diminished greatly. Secondly, during bright sunshine, the volume varied little. Thirdly, in the autumn, and during cloudy weather, when the leaves are falling, and when the decaying plants yield large quantities of carbonic acid, the volume of the gas in the atmosphere of the experiments diminished considerably. Fourthly, during the warmer winter months, which are favourable to decomposition, the volume of carbonic acid which disappeared from the atmosphere of the experiments was great; but during frosty weather, the temperature being kept nearly uniform, the loss of carbonic acid was very trifling.

I next proceeded to examine the contents of the retorts. The retorts containing the soils were placed in mutton suet, which was gradually raised in temperature to 300° Fahrenheit. The carbonic acid that was expelled, was not more than had filled the interstices of the earth.

The different soils in the retorts, together with the duplicates which had been preserved in bottles, were experimented upon in the following manner:—Equal portions by weight were placed in tubes standing over mercury. On introducing to each pyroligneous acid, the volume of carbonic acid given off from the samples of earth which had been kept in the retorts, was smaller than that from those in the bottles.

On subjecting to ultimate analysis, with black oxide of copper, other portions of these earths, the quantity of carbon obtained from the contents of the retorts, exceeded that from the contents of the bottles. But the excess was not more than might fairly be allowed for, as the result of accidental or incidental causes affecting the experiments.

On agitating other portions in water, and allowing the insoluble matter to subside, the clear liquid obtained from the earth, in the retorts which had been exposed to carbonic acid, was more alkaline, was of higher specific gravity, and on being kept in open vessels for several weeks, became much darker in colour, than that obtained from the samples of earth which had been kept in the bottles.

The seeds planted in these earths, and similarly treated in every respect, germinated and grew more luxuriantly in the earth which had been exposed to the acid gas.

These experiments, imperfect as they are in some respects, inclined me to suppose that a portion of the carbonic acid given off by the roots of plants, may disappear by a process secret to us, and thus render the land more productive. They inclined me also to suppose that the disappearance of this gas from the atmosphere, is accompanied with the formation of alkaline and other soluble matter, which becomes dark-coloured by exposure to the atmosphere, but they throw no light upon the influence which living plants have on its disappearance from the atmosphere.

It is probable, that the carbonic acid which is imparted to the atmosphere by the leaves and stems of plants, very far exceeds that given off from any other source. This is evidenced in the examination of the air, at remote distances from animal respiration, combustion, &c. in a still night in summer.

The experiments described page 58, shew that the volume of carbonic acid given off is very considerable. The average quantity given off from a turf clothed with grass was 3·5 per cent. of an abundant annual crop; that which proceeded from the strawberry plant was 3·7 per cent. for each night.

It is also shown at page 50 that sixty pounds of carbon is contained in the carbonic acid which disappears in a few hours from the atmosphere, resting upon each acre of the earth's surface; and at page 51, the carbonic acid added to the same atmosphere in a few hours in one night, contained one hundred and seventy-five pounds of carbon — a quantity, equivalent to that made by the plants growing upon an acre of productive land in twenty days.

By passing an atmosphere containing from five to ten per cent. of carbonic acid, through vessels in which healthy plants are growing, a considerable portion of it disappears; but when the proportion is about one per cent. the acid which is removed is scarcely appreciable; and when its proportion is from $\frac{1}{500}$ to $\frac{1}{300}$, a proportion approximating to that contained in the surrounding air, the plants, as every experiment testifies, rather increase the proportion than take from it. We have, therefore, no just reason for supposing that in ordinary vegetation, much of the carbon which is given off by plants in the night is assimilated by them during the day. This has also been verified by experiments pages 91, 95, where it is shown that when plants grow in an atmosphere containing more than the usual proportion of carbonic acid, the carbon which is assimilated by them, bears but a small proportion to that which disappears from the air. The results of all these experiments warrant the conclusion; that much of that sixty pounds of carbon which disappeared in a few hours from an acre of land, did not enter into the constitution of the plants which grew upon the same; and that much of that which is imparted to the atmosphere by plants, passes off in a manner not shown by any of our experiments.

M. de Saussure is inclined to ascribe the disappearance of carbonic acid in a great measure to moisture; he says, "The principal cause of the variation in the carbonic acid in the atmosphere at different seasons, and at the same seasons of different years, is the moisture of the earth occasioned by rain, which probably diminishes this gas by absorbing it, or it is absorbed by the earth. We get comparatively very insignificant results if we content ourselves with merely comparing two or three dry days with two or three wet ones. Rain only acts slowly upon the air; a heavy rain does not appear immediately to diminish the carbonic acid. The examples which are given on the effect of rain, offer anomalies; but they are explained, however, when we take into consideration, that the quantity of carbonic acid in one month, is subordinate to that of the preceding months." *

The variations, in the proportion of carbonic acid in the atmosphere, being generally greater during a

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* Saussure's Memoir, page 26.

period of two or three days than during a month; consecutive experiments, made for several days or weeks, cannot be taken as a correct criterion for determining any principle, connected, either with the appearance or disappearance of this gas from the air.

The greatest monthly difference in Saussure's experiments is in July and August, 1829; that in the former was 4·33 parts in 10,000, and that in the latter 3·8, making a difference of ·53 parts. Thi difference is small when compared with that which occurs in a few days at different, or the same seasons of the year. On the 18th Dec. 1829, the proportion was 4·04, and on the 24th it was only 3·36, giving a difference of ·68; and on the 26th of the same month it was 4·22, giving for the variation ·86. On the 25th of July, of the same year, the proportion was 4·45, on the 8th of August, 3·22; giving a difference of 1·22.

We have also similar variations taking place diurnally. On the 26th of August, 1828, the proportion at 4 P. M. was 4·20, at 3 A. M. of the following day 5·74, the weather being fair and clear. These gave for the variation 1·54 in 10,000.

That the theory of rain removing the principal part of the carbonic acid from the atmosphere may be enquired into, we shall take the monthly variations above mentioned, and see what proportion the volume of the carbonic acid bears, to that of the rain which falls upon the earth.

The rain which fell at Geneva, three quarters of a league distant from Chambeisy, the place where the air experimented upon was collected, was, in the month of August, 4·5069 inches, making the quantity upon each acre 28,227,000 cubic inches. The carbonic acid which is shewn to have disappeared from the atmosphere during the same period is ·53 parts in 10,000 volumes. Rain water we find by experiment contains from $\frac{1}{1000}$ to $\frac{1}{500}$ of its volume of this gas. That which fell upon one acre of land in the month of August would therefore contain from 28,227 to 56,454 cubic inches.

On the supposition that the removal of carbonic acid did not take place throughout the entire atmosphere, but only throughout one thousand feet from the earth, the volume of carbonic acid which disappeared in August would be 4,093,100 cubic inches,—one-seventh of the volume of the rain water, and one hundred times more than it is found to contain, leaving the disappearance of the remaining 99 per cent. to be accounted for by some other process.

It is probable that the most accurate calculations we can make upon the subject of rain removing carbonic acid from the atmosphere, are those based upon the depth of rain which falls, holding in solution about $\frac{1}{500}$ of its volume of this gas. Taking this for granted, the depth of the annual fall of rain is from seventeen to twenty-three inches, making a mean of twenty inches. In conformity with this data, that which falls upon an acre of land, will bring down with it nearly 300,000 cubic inches of carbonic acid, containing about 5·6 lbs. of carbon, one four-hundredth of an average annual crop from productive land. This 5·6 lbs. of carbon, (which in all probability is more than is included in the carbonic acid deposited by rain in any year upon each acre of the earth's surface), does not exceed ·04 part of carbonic acid in 10,000 parts by volume of the surrounding atmosphere one thousand feet high,—a quantity, not exceeding what disappears from the atmosphere, in many instances, in a few hours.

These considerations, render it unnecessary to examine any other experiments, as to the removal, by rain, of much of that carbon from the atmosphere which enters into the constitution of plants. From them we may safely infer, that the carbonic acid removed from the atmosphere by rain is very small; and we conclude from this part also of the research, that the principal part of the carbonic acid which disappears from the atmosphere, is by a process unknown to us. De Saussure's observations, as well as the results of my own experiments lead me to suppose, that this unknown process is most actively at work during damp weather and light showers.

## THE CARBONIC ACID WHICH PROCEEDS FROM COMBUSTION.

There is not so much difficulty in ascertaining the quantity of carbonic acid imparted to the atmosphere by combustion, as we experience with respect to that given off by plants. In the latter case our experiments are conducted by placing the plants in limited atmosphere, where they are excluded from the ordinary influence of the air. But we can subject a body to ultimate analysis by combustion, and determine accurately the volume of carbonic acid which will be given off to the ordinary atmosphere.

We may form an idea of the quantity of carbonic acid imparted to the atmosphere of this country, from the fact, that 2,909,144 tons of sea borne coals were imported into London in the year 1841, which would yield to the atmosphere about 8,800,000 tons of carbonic acid, containing 2,400,000 tons of carbon, and though a portion of that coal would be consumed out of the counties of Middlesex and Surrey, yet, taking into account the quantities of canal coal, wood, oil, tallow, and other combustibles burned in these counties, we may fairly reckon that 2,400,000 of carbon is yielded to these atmospheres every year by combustion; this would, according to the census of 1841, give a proportion of 1·116 ton of carbon for each individual in these counties. The proportion throughout England, I believe to be somewhat greater; but taking at 1·116 for each individual, this gives for a population of 15,911,725 persons, 17,757,485 tons of carbon imparted to the atmosphere of England by combustion. This computation, I have no doubt, is much below the truth, if we could accurately reckon all the different sources from which carbon is given off by combustion, the total quantity would be found equal to, if not exceed, that in the plants which grow upon the land in this country in one year, and which I estimate at 22,160,000 tons.

## THE CARBONIC ACID GIVEN OFF BY ANIMALS DURING RESPIRATION AND PERSPIRATION.

During every act of breathing, a portion of atmospheric air is inhaled, and a nearly similar portion returned back to the surrounding atmosphere. The air breathed in, is constituted of about 79 per cent. of nitrogen, 21 of oxygen, and about $\frac{1}{200}$ of carbonic acid. The expired air is found to contain about the same proportion of nitrogen, from 14 to 17 of oxygen, and from 4 to 7 per cent. of carbonic acid, and a considerable proportion of moisture. The principal change effected upon the atmosphere, by the operation of breathing, appears to be, that a portion of the oxygen combines with the carbon, and forms carbonic acid.

The quantity of carbonic acid which is given off per day, by a full-grown person, was estimated by Sir H. Davy at 17,811 cubic inches, containing 4,853 grains of carbon; by Messrs. Allen and Pepys at 18,612 cubic inches, containing 5,148 grains, making a mean of 5000 grains of carbon, given off to the atmosphere each day, by a full-grown person.

Assuming 3,500 grains, as the weight of carbon in the carbonic acid imparted to the atmosphere, on each day, by each individual, the weight of carbon given off, by the inhabitants of England, according to the census of 1841, would be, for that year, 1,854,900 tons of carbon, contained in the air given off by them. And, assuming the other animals yield double the quantity the weight of carbon in the carbonic acid given off to the atmosphere, by animal respiration, would be 5,564,700 tons. If to this we add that carbon in the carbonic acid, which is given off during animal perspiration, we shall not be much in error, if we call the total weight of carbon in the atmosphere, communicated by animal respiration and perspiration, 6,000,000 tons annually, being a quantity equivalent to 27 per cent. of that which is produced annually by the land in England.

Unless we admit that animals, as well as vegetables, have the power of making carbon, the carbon supplied to the air by animal respiration and perspiration, may be regarded as forming a part of the produce of the land, indirectly communicated by the operations of the animal functions. Intimately connected with this subject, is the

## CARBONIC ACID GIVEN OFF DURING FERMENTATION, AND THE DECAY OF ORGANIC MATTER.

All animal and vegetable bodies, which constitute what is here denominated organic matter, undergo fermentation, or pass into decay, when kept in a state of moisture, and exposed to a temperature whose limits lie between 36° and 120° Fahrenheit, the mean between these two extremes being the most favorable to this change. The gaseous products which result from these chemical actions, so far as the carbon in both the animal and vegetable matter is concerned, are carbonic acid principally, with an almost inappreciable portion of carburetted hydrogen.

For our present purpose we may suppose, that all the organic matter which passes into decomposition, derives its carbon, either directly or indirectly, by means of digestion, from the vegetable world.

Assuming, that the quantity of organic matter, animal and vegetable, is stationary, the quantity which is destroyed must be equal to the quantity produced in each year. If, in any one year, in England, animal and vegetable matter is produced, containing 22,000,000 tons of carbon, a like quantity must be destroyed. Of this we have seen, that about 6,000,000 passes off by the breathing and perspiration of animals; the rest (with some deductions for what is destroyed by combustion) is destroyed by decomposition, and gives off 16,000,000 tons of carbon, minus the quantity by combustion.

These considerations, although not strictly speaking correct, as we shall have occasion to notice hereafter, will serve in this stage of our inquiry, to convey an idea of the quantity of carbonic acid imparted to the atmosphere during the decomposition of organic matter.

## CARBONIC ACID GIVEN OFF FROM VOLCANOES, FISSURES IN THE EARTH, AND WATER-SPRINGS.

We have no means of ascertaining the quantity of carbonic acid imparted to the atmosphere by volcanoes, nor through the various fissures in the earth; neither can we form any correct idea of that which proceeds from springs, some of whose waters contain it in large quantities. "Bischof calculated that the springs of carbonic acid in the *Eifel* (a volcanic disstrict near Coblentz), send into the air every day, more than 90,000 lbs. of carbonic acid,"* corresponding to 25,200 lbs. of carbon. These springs will impart to the atmosphere annually, more than 9,000,000 lbs. of carbon, a quantity equivalent to the produce of 5000 acres of land, of an average quality.

Although we cannot speak definitely, as to the quantity of carbonic acid which proceeds from these sources, there can be no doubt that this largely contributes to the carbonic acid of the atmosphere.

* Liebig, page 69.

The atmosphere of England, therefore, derives from these different sources, viz:—

| | Tons of Carbon. |
|---|---|
| From plants during their growth, at least | 22,160,000 |
| From combustion of coal, &c. | 17,757,485 |
| From breathing and perspiration of animals | 6,000,000 |
| From decomposition of organic matter | 16,000,000 |
| Total | 61,917,485 |

besides that given off by volcanic agency, fissures in the earth, springs, the burning of lime-stone, &c.

The amount of carbonic acid from these different sources, will vary in the different parts of the globe; with the climate, state of agriculture, the population, the number and species of animals, the manufactures, &c. The entire volume imparted to the atmosphere, in each year, on a very low estimate, will contain, at least, three times as much carbon as is in the plants yielded by the land.

Now, this being the case, and no appreciable accumulation of this gas being found in the atmosphere, by what process of natural chemistry is all this carbonic acid removed from the atmosphere? It is true that it disappears under the influence of plants from an artificial atmosphere surcharged with this gas; but when the plants are kept in the common atmosphere, the proportion of carbonic acid is generally, if not always increased. The artificial atmosphere is injurious to the plants; in the natural atmosphere they grow luxuriantly, and arrive at maturity. The effects of vegetation upon the natural atmosphere, clearly does not help to account for the disappearance of this enormous quantity of carbonic acid; all reasoning from this fact, must therefore lead us to the conclusion, that instead of the proportionate volume of carbonic acid decreasing, it must necessarily increase, if no other way be found for its disappearance. But supposing its effect upon the artificial atmosphere afforded better data to go upon, and even supposing with Professor Liebig that plants derive their carbon exclusively from the carbonic acid in the atmosphere, and that they remove all that which disappears,—the weight of carbon in the carbonic acid which disappears from the atmosphere, being three times that found in the constitution of the plants, they only assimilate one-third,—what then becomes of the two-thirds? Do they deposit this two-thirds in the earth? Then the earth, instead of being impoverished by the growth of plants, will be enriched every year by twice as much carbon as is comprised in the plants it produces. Do they give it back to the atmosphere? We find by experiment that the volume of carbonic acid given off by plants to the surrounding air, contains in some instances, twice as much carbon as the plants themselves; but if they remove the whole of what disappears, and only assimilate one-third, there would be an annual increase of carbonic acid in the atmosphere, containing twice as much carbon as the plants which grow upon the earth. As we have no reason to suppose that there is an annual increase of carbonic acid in the atmosphere, we must conclude that the principal part of the carbonic acid in the surrounding air is not removed by plants, but that it disappears by some other process.

M. de Saussure, who has so ably investigated this subject, finding that the influence of vegetation, temperature, and humidity of the soil, were insufficient to account for the variation of the carbonic acid in the atmosphere, thinks, that what is wanting in these respects is made up by atmospheric electricity. He says:—

"First. Atmospheric electricity is stronger during the day than during the night.

"Secondly. Electricity is stronger in winter than in summer.

"Thirdly. It is much more rare to find electricity in the nights of summer than in the nights of winter.

"Fourthly. Electricity is not so strong on the mountains as in the plains.

"Fifthly. High winds generally diminish the intensity of atmospheric electricity."

This brings us but little nearer to a solution of the difficulty: for, admitting that atmospheric electricity is the agent by which this acid is decomposed, and that its oxygen is left in the atmosphere, what becomes of the carbon? That it ceases to exist as carbon, is demonstrated by experiment; but how electricity, or any other agent, effects its destruction, is a problem yet unsolved.

If chemists would make experiments more resembling the processes of nature, and take into account practical results, I think they would find in the various physical facts and deductions, enough to convince them, that all the carbonic acid which disappears from the atmosphere, does not enter into the constitution of the plants which grow upon the earth, and that a large portion of it disappears by some other and unknown process; and that plants, by a process equally unknown, make carbon, and furnish to the atmosphere fresh carbonic acid in compensation for that which disappears from it.

## THE PROPORTION IN WHICH PLANTS MAKE CARBON UNDER VARIOUS CIRCUMSTANCES.

We shall now consider the power which plants possess of making carbon, and how its production is affected by the different circumstances under which the plants are placed.

Seedling plants that have germinated and grown in the open air, without being covered with earth, contain less carbon than the seeds from whence they sprung.

1,000 grains of barley were placed in water, and kept for 48 hours at a temperature varying from 45° to 50°, increased 464 grains in weight. These seeds were allowed to germinate in a bottle loosely corked. They were shaken every twelve hours; almost every seed germinated.

On the fourteenth day, the whole was made into malt by drying at a temperature under 300°. When this malt had been exposed to the surrounding air for twenty-four hours, its weight, including the rootlets, was 912 grains, and was constituted of .

| | Carbon. | Hydr. | Oxygen. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| Malt and rootlets.......... | 371· | 55·6 | 455·7 | 16·6 | 13·1 | 912 |
| Barley before it was steeped | 397·5 | 61·5 | 517·0 | 13·8 | 13·0 | 1000 |
| | − 26·5 | − 5·9 | − 61·3 | + 2·8 | + ·1 | − 88 |

Showing a loss of 26·5 grains of carbon, equal to 6·6 per cent.

Another similar experiment was allowed to germinate and grow until many of the plumulas had passed through the seeds. The malt, rootlets, and plumulas, weighed 893 grains, and were constituted of—

| | |
|---|---|
| Carbon | 362 |
| Hydrogen | 54 |
| Oxygen | 444 |
| Nitrogen | 20 |
| Ashes | 13 |
| | 893 |

Showing a deficiency of 35·5 grains of carbon, nearly equal to 10 per cent.

A third experiment was occasionally supplied with water, and allowed to grow until most of the seeds appeared to be deprived of their farinaceous matter. The plants, together with the husks and rootlets, weighed, when dried and subjected to analysis, 641 grains, and were constituted of—

| | |
|---|---|
| Carbon | 287·3 |
| Hydrogen | 36·5 |
| Oxygen | 285·5 |
| Nitrogen | 18·4 |
| Ashes | 13·3 |
| | 641· |

Showing a loss of 110·2 grains or 27·5 per cent. of carbon.

On the 18th of April, 96 early peas, weighing 300 grains, were planted in a flat-bottomed glass dish, and supplied with filtered river water. On being kept at a temperature varying from 58° to 66°, they germinated in three days. During the period of their growth (38 days) they remained about half the time in a green-house, and were supplied with the same kind of water; they were afterwards kept in the open air, when they derived their moisture from rain. The plants grew most luxuriantly for 30 days, when every leaf and stem was so fully developed with a promise of flowering, that I felt satisfied that these plants contained more carbon than was originally contained in the seeds. The three last days the plants made no progress. At the bottom of the stem there were a few faded leaves, and the roots appeared to be dead. The entire plants and the husks, when dried, weighed 256 grains, and were

| | Carbon. | Hydr. | Oxygen. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| Constituted of........ | 95·92 | 14.38 | 124·51 | 10·44 | 10·75 | 256 |
| Constitution of the seeds planted.... | 115·98 | 19·89 | 149·24 | 11·19 | 3·60 | 300 |
| | –20·06 | –5·51 | –24·73 | –·75 | +7·15 | –44 |

Giving a loss of 20·06 grains of carbon, equal to 17·9 per cent.

When other seeds were made the subject of similar experiments, and allowed to grow until most of the nutritive parts had disappeared, and when in some instances the third leaf had made its appearance, a loss of carbon was always sustained.

| | | |
|---|---|---|
| Those with wheat gave a loss from | 30 to 40 | per cent. |
| Those with oats .. .. | 18 to 20 | „ |
| Those with turnip seed .. | 10 to 20 | „ |
| Those with rape .. .. | 15 to 25 | „ |

When the two last-mentioned kinds of seeds are experimented upon, the loss of carbon is very various, owing more particularly to so many more germinating in some experiments than in others.

The first experiment may be regarded as shewing the loss of carbon sustained on converting barley into malt. The third, and those of the other seeds, represent what takes place when seeds are placed upon the surface of the earth, or planted in the ground, so long as the plants are dependent upon the seeds for support.

It would appear, that when plants are deriving nourishment from the seeds, they draw very little from the organic matter which surrounds them. This is apparent from seeds, which are planted in earth from whence they can draw no organic matter, germinating, in most instances sooner, and growing quicker than those planted in a similar kind of earth, containing organic matter, indicating, that the nourishment afforded by the seeds to the young plants, is better suited to their purposes than any other form of matter. One exception to this rule is, when seedling plants grow in an atmosphere impregnated with miasma.

The following experiments were made with a view to ascertain, if the whole of the carbon which disappears during the germination of seeds, and the early growth of the plants, passes off in the form of carbonic acid gas.

The first experiment was made on the 14th of March, with 500 grains, in weight, of red wheat, constituted of—

| | |
|---|---|
| Carbon ................ | 194·8 |
| Hydrogen .............. | 34·2 |
| Oxygen ................ | 256·3 |
| Nitrogen .............. | 6·1 |
| Ashes.................. | 8·6 |
| | 500 |

which, on being kept in distilled water 36 hours, absorbed 225 grains. These seeds were placed on a glass plate, standing upon mercury, which covered the bottom of an air-tight dish, whose diameter was eight inches. One graduated measure, on which the $\frac{1}{1000}$ of a cubic inch could be read, was supported vertically amongst the seeds, and another was placed on the mercury in an horizontal position. Over this glass plate, seeds, and tubes, a bell-glass was inverted, whose content was 401 cubic inches.

When the seeds had germinated, and sent forth stems, about half an inch in length, the experiment was placed where the sun shone upon it about six hours each day. During the first twelve days, the temperature varied from 45° to 49°; and the remainder of the time, it was generally from 48° to 60°, except on two occasions, when it rose from 58° to 65°.

The space occupied by the glass plate, seeds, tubes, and mercury, would, upon an average, be nearly 10 cubic inches, making the volume of the gas in the apparatus 391 cubic inches.

Previously to examining the experiment on each occasion, a portion of gas was extracted from the bottom part, by means of a syringe, and transferred to a graduated tube standing over mercury. On removing the bell-glass, the two enclosed tubes were immediately placed in the mercurial trough. Three different samples of the gaseous contents of the apparatus, viz., two taken from the bottom, and one from two inches of the top, were made subjects of separate analysis. The experiment was re-arranged with other graduated tubes, the plants were supplied with distilled water and fresh atmospheric air; and the bell-glass, after being freed from its former gaseous contents, was replaced on the mercury.

At each examination, the volume of the gaseous products in each tube was noted, the carbonic acid gas removed, and its proportion registered. The following are the results, at 30° barometer, and 60° temperature:—

| | | Cubic inches of carb. acid. |
|---|---|---|
| March 26th, | Most of the seeds had germinated ............ | 32·3 |
| „ 31st, | The plants had a healthy appearance; the stems an inch in length...... | 51·3 |
| April 3rd, | Plants all healthy; about three inches in length .. | 56·0 |
| „ 6th, | Plants about 3 inches in length; some unhealthy | 53·5 |
| „ 9th, | Plants about four inches in length; many of them having a sickly appearance ................ | 29.7 |
| | | 222·8 |

in the apparatus. On deducting one per cent., for carbonic acid in the atmosphere, at each time the apparatus was re-adjusted, we have 203·3 cubic inches, containing 26·58 grains of carbon, as a product of the experiment during the germination of the seeds, and the growth of the young plants.

On the 9th of April, a flat vessel, containing concentrated sulphuric acid, was introduced under the bell-glass, where it remained for two days, when the water was all dried up, and the plants were deprived of much of their moisture. The sulphuric acid was not darkened in colour, neither had any appreciable volume of carbonic acid been given off to the atmosphere. The plants, roots, and husks, not being dried by this desiccating process, so that they could be reduced to a powder, were placed on thin paper, and dried at 130°: they were afterwards exposed for twenty-four hours, when their weight was 371 grains. In this state, the whole was reduced to a powder; and on being analyzed, gave—

| | | |
|---|---|---|
| Carbon | 39·62 | 146·99 |
| Hydrogen | 6·25 | 23·19 |
| Oxygen | 49·16 | 182·40 |
| Nitrogen | 2·71 | 10·05 |
| Ashes | 2·26 | 8·37 |
| | 100 | 371· |

On recapitulation, this experiment gave—

| | Carbon. | Hyd. | Oxy. | Nitro. | Ashes | Total. |
|---|---|---|---|---|---|---|
| April 9, Plants, &c. | 146·99 | 23·19 | 182·40 | 10·05 | 8·37 | 371 |
| „ Carb. Acid | 26·58 | .. | 69·65 | .. | .. | 96·23 |
| Total | 173·57 | 23·19 | 252·05 | 10·05 | 8·37 | 467·23 |
| Mar. 14, Seeds | 194·8 | 34·2 | 256·3 | 6·1 | 8·6 | 500· |
| | −21·23 | −11·01 | −4·25 | +3·95 | —·23 | −32·77 |

a loss of 21·23 grs. of carbon, equal to 10·89 per cent. upon the quantity of this body in the experiment at the commencement.

Having reason to suppose that a still greater loss of carbon would be sustained, if the plants were kept in the shade, I made the following experiment on the 11th of April, with 300 grains of the same kind of wheat, and conducted in every respect in the same manner as the last, except, that it was kept during the whole period out of the direct influence of the sun's rays; and, after the first eight days, at a temperature which did not vary more than three degrees Fahrenheit.

The seeds, the vessel which contained them, and the mercury, occupied, upon an average, about 11 inches, leaving 390 cubic inches for the volume of the air in the apparatus. The following is the volume of carbonic acid, at 30 bar. and 60 temp., obtained at each examination.

| | |
|---|---|
| April 18 | 22·0 cubic inches. |
| „ 25 | 59·5 „ |
| „ 30 | 75·0 „ |
| May 5 | 62·1 „ |
| | 218·6 „ |

If from this we deduct one per cent. for carbonic acid in the atmosphere at each time the experiment was examined, we have for the carbonic acid found in the apparatus 203 cubic inches, containing 26·53 grains of carbon. By the process of desiccation 2·2 cubic inches of carbonic acid was obtained, containing ·29 of a grain of carbon.

The young plants, whose length was about five inches, were slender, of a pale green colour, appeared unhealthy, and had a faint smell. They had exhausted about three-fourths of the farinaceous part of the seeds; that which remained was acid.

The plants, roots, and remaining portions of the seeds were finally dried at a temperature not exceeding 120°, and afterwards exposed for twenty hours, when their weight was 171·6 grains. In this state the mixture was constituted of—

| | | |
|---|---|---|
| Carbon | 39·62 | 67·99 |
| Hydrogen | 7·04 | 12·08 |
| Oxygen | 47·42 | 81·37 |
| Nitrogen | 3·18 | 5·46 |
| Ashes | 2·74 | 4·70 |
| | 100· | 171·6 |

On a recapitulation of the products of this experiment, we have—

| | | Car. | Hyd. | Oxy. | Nitro. | Ash. | Total. |
|---|---|---|---|---|---|---|---|
| May 5. | Plants, roots, &c.... | 67·99 | 12·08 | 81·37 | 5·46 | 4·7 | 171·6 |
| | Carbonic acid .... | 26·53 | .. | 70·03 | .. | .. | 96·8 |
| | Ditto ............ | ·29 | | | | | |
| | Total ........ | 94·81 | 12·08 | 151·40 | 5·46 | 4·7 | 268·4 |
| April 11.— | Seeds ...... | 116·88 | 20·52 | 153·57 | 3·66 | 5·16 | 300· |
| | | —22·07 | —8·44 | —2·17 | +1·8 | —·46 | —31·6 |

This decrease of 22·07 grains of carbon is equivalent to 18·9 per cent.

Upon the supposition that 22·07 grains of carbon disappeared as carbonic acid, there must have been formed, during the germination of these seeds and the growth of these young plants, 47 cubic inches of this gas, more than was found in the experiment.

The loss of carbon in these experiments is another instance which may be added to those already adduced in support of the disappearance of this body by a process secret to us. They also teach us that when seeds fall upon the earth, but do not take root in it, although they may be plentifully supplied with water, the quantity of carbon they yield will be less than that contained in the seeds; but, it may be observed, that in such cases there is a gain of nitrogen when compared with that in the seeds.

## PLANTS MAKE CARBON DIFFERING IN PROPORTIONS WITH THE EARTHS IN WHICH THEY GROW.

When seeds are planted in moistened earth, their germination is partially retarded, when compared with those which germinate without earth. When the young plants which are surrounded by earth have exhausted the seeds, the carbon in the carbonic acid given off during their growth, together with that in the different parts of the plants and in the husks, exceeds that originally contained in the seeds. This increase of carbon varies with the kind of earth in which the seeds are planted, as is illustrated in the following experiments. The loss of carbon, shown in the two experiments last described, is prevented when the seeds are planted in powdered flint glass, kept moistened with distilled water. On the 26th of March, 11 seeds of wheat (10 grains by weight), constituted of—

| | |
|---|---|
| Carbon . . . . | 4·024 |
| Hydrogen . . . | ·670 |
| Oxygen . . . . | 5·012 |
| Nitrogen . . . | ·122 |
| Ashes . . . . | ·172 |
| | 10· |

were planted in 4,000 grains of wet glass in coarse powder, resting upon a watch glass introduced into an inverted lamp glass, standing on mercury covered with water; over which was a tall jar, whose content was 91 cubic inches. Eight inches of atmospheric air was extracted; and the same volume of mercury, covered with one-tenth of an inch of water, supplied its place. The volume of air in the jar, the barometric pressure, and the temperature were registered, and the experiment was placed where the sun shone about half the day, and kept at a temperature varying from 55° to 65°.

On the 2nd of April, ten young healthy plants appeared above the powdered glass. On the 9th of April, at 8 A.M., the plants were two inches long:

4·02 cubic inches of carbonic acid was removed by introducing liquor potassa under the jar, which remained for four hours. The jar was then removed, fresh atmospheric air admitted to every part of the apparatus, and the experiment readjusted. On the 20th of April, at 8 A.M., ten of the plants, each having two leaves, looked healthy, and were about eight inches high: 4·7 cubic inches of carbonic acid were removed in the manner above described, and the apparatus re-arranged. April 27th, the plants had not increased their number of leaves; they assumed a sickly appearance: 2·1 cubic inches of carbonic acid was absorbed, by liquor potassa; making a total of 10·82 cubic inches; and which, after making allowance for the carbonic acid in the atmosphere and the barometer and thermometer corrections, would make the volume due to the experiment 8·62 cubic inches, containing 1·12 grains of carbon.

The plants, when dried, weighed 2·0 grains; the roots and husks were carefully removed from the powdered glass, dried, and when mixed with the plants and powdered, weighed 7·92 grains. This mixture, on being analyzed, gave—

| | |
|---|---|
| Carbon . . . . | 2·92 |
| Hydrogen . . . | ·53 |
| Oxygen . . . . | 4·12 |
| Nitrogen . . . . | ·14 |
| Ashes . . . . | ·21 |
| | 7·92 |

The weight of carbon in the carbonic acid, plants, roots, and husks is 4·04 grains; being an increase of ·016 of a grain, equivalent to ·4 per cent.

Experiments made with the same kind of seeds, conducted in every respect similarly to the one last described, and on substituting powdered stone-ware for the powdered glass, gave results indicating a greater increase of carbon, when compared with that in the seeds experimented upon.

The seeds were planted in 2,000 grains of powdered stone-ware, which had been previously moistened with distilled water. The content of the jar which enclosed this experiment was 69 cubic inches.

The seeds in this experiment all germinated; the plants looked more healthy than those which had grown in the powdered glass, attained a greater height, and seven of them had, on the day of final examination, three leaves each.

| Date. | | Time. | | Carbonic acid removed. |
|---|---|---|---|---|
| April 9 | .. | 8 A.M. | .. | 6·01 cubic inches. |
| „ 20 | .. | „ | .. | 6·31 „ |
| „ 27 | .. | „ | .. | 3·41 „ |

which, on making allowances for diminished pressure, temperature, and carbonic acid in the atmosphere, gave 14·1 cubic inches for the carbonic acid found in the experiment, containing 1·84 grains of carbon.

The plants, when dry, weighed 2·4 grains; the roots and husks, on being removed and dried, weighed, when mixed with the plants, 6·23 grains, and were constituted of—

| | |
|---|---|
| Carbon . . . . | 2·33 |
| Hydrogen . . . | ·40 |
| Oxygen . . . . | 3·11 |
| Nitrogen . . . . | ·14 |
| Ashes . . . . | ·25 |
| | 6·23 |

On a recapitulation of the products, we have this experiment giving—

| | Car. | Hyd. | Oxy. | Nitro. | Ash. | Total. |
|---|---|---|---|---|---|---|
| In the carbonic acid.. | 1·84 | .. | 4.81 | .. | .. | 6·65 |
| In the plants, &c .... | 2·23 | ·40 | 3·21 | ·14 | ·25 | 6·23 |
| Total...... | 4·07 | ·40 | 8·02 | ·14 | ·25 | 12·88 |
| In the seeds ........ | 4·024 | ·67 | 5·012 | ·122 | ·172 | 10· |
| | + ·046 | —·27 | + 3·008 | + ·018 | + ·078 | + 2·88 |

exhibiting a gain of ·046 of a grain, equal to 1·1 per cent. of carbon. Had the stone-ware, after the plants were removed, been subjected to analysis, other experiments lead me to suppose, that a small portion of carbon would have been obtained; making the increase of carbon, upon that in the seeds experimented upon, more than is shown.

The next experiment which I shall describe shows that when the seeds are planted in silicious sand, the increase of carbon is in higher proportion, than when powdered glass or stone-ware is employed. The sand used on this occasion yielded no carbonic acid gas by the addition of acids; it was first placed in a crucible kept at a red heat for an hour, and frequently stirred during the time. When cold, one pound of it was placed in a common flower-pot, and moistened with distilled water. On the 15th of March, 62 seeds of wheat, weighing 50 grains, were planted in this sand. The experiment was then fitted up in the manner described in page 63. A glass shade, content 206 cubic inches, covered the experiment, which was placed where the sun shone upon it about one half the day, and where the temperature varied from 50° to 65°.

The atmosphere was examined every seventh day, at 8 A. M., by removing the carbonic acid by liquor potassa. The seeds all germinated and grew luxuriantly, many of them having three, and some four leaves. On the 28th day, some of the leaves were brown. The plants were cut off near the surface of the sand, and the apparatus re-adjusted. Fresh shoots made their appearance. In fourteen days the young shoots showed signs of decay. They were cut off, and when added to the others, the whole weighed when dried 14·6 grains, and were constituted of—

| | |
|---|---|
| Carbon | 6·12 |
| Hydrogen | ·75 |
| Oxygen | 6·23 |
| Nitrogen | ·38 |
| Ashes | 1·12 |
| | 14·6 |

When the sand was dried at a temperature not exceeding 150°, 22·4 grains of roots, stems, and husks were separated. These were constituted of—

| | |
|---|---|
| Carbon | 8·44 |
| Hydrogen | 1·02 |
| Oxygen | 8 40 |
| Nitrogen | ·34 |
| Ashes | 4·20 |
| | 22·40 |

On subjecting a portion of the sand to analysis, as much carbon was obtained as gave for the whole experiment 2·86 grains.

On making an allowance of one per cent. for the carbonic acid in the atmosphere at each examination of the experiment, there remained 58 cubic inches as the product of the experiment, containing 7·68 grs. of carbon. This experiment gives—

| | | |
|---|---|---|
| | 6·12 | grs. of carbon in the plants. |
| | 8·44 | do. do. in the stems, roots and husks. |
| | 2·86 | do. do. in the earth. |
| | 7·68 | do. do. in the carbonic acid. |
| | 25·10 | |
| | 20·12 | originally in the seeds. |
| Increase | 4·98 | equivalent to 24·7 per cent. |

The fourth experiment was made September 14, with 63 seeds of the same kind of wheat, weighing 50 grains, which were planted in one pound of equal proportions of sand and clay, prepared by burning, and tested by acids, in the manner already described, and watered with distilled water.

This experiment was placed under a glass globe whose content was 401 cubic inches. All atmospheric communication was cut off by water. It stood where the sun shone about one half the day, in a room not artificially heated.

The following is the registered account of the carbonic acid found in the apparatus at each examination:

| | | | | |
|---|---|---|---|---|
| Sept. | 23, | 8 A. M., | 16·8 | cub. in. of carb. acid, plants an inch in length. |
| | 29, | 6 ,, | 22·6 | ,, ,, four inches. |
| Oct. | 6, | 7 ,, | 14·5 | |
| | 23, | 7 ,, | 8·0 | 3 leaves on most of the plants. |
| | 29, | 7 ,, | 9·8 | ..plants fading—cut down. |
| Nov. | 9, | 8 ,, | 8·2 | ..fresh shoots 2 inches long. |
| | 11, | 8 ,, | 3·4 | ..the experiment broken up. |
| Total | | | 83·3 | cub. inches, containing 10·89 grains of carbon. |

The plants in this experiment grew vigorously until the 25th of October, when some of the leaves began to fade. On the 29th they were cut off about half an inch above the earth. Fresh shoots made their appearance on the same day. These continued to grow until the 8th of Nov., when they began to droop and fade.

These second shoots were cut off and mixed with the former; conjointly they weighed when analyzed 22·3 grains, constituted of—

| | | |
|---|---|---|
| Carbon | 37·39 | 8·34 |
| Hydrogen | 5·89 | 1·31 |
| Oxygen | 46·45 | 10·36 |
| Nitrogen | 3·77 | ·84 |
| Ashes | 6·50 | 1·45 |
| | 100· | 22·3 |

The roots, parts of stems, and husks, separated from the earth when dry, weighed 27·2 grains and were constituted of

| | | |
|---|---|---|
| Carbon | 24·32 | 6·6 |
| Hydrogen | 3·80 | 1·1 |
| Oxygen | 29·85 | 8·1 |
| Nitrogen | 2·43 | ·7 |
| Ashes | 39·60 | 10·7 |
| | 100· | 27·2 |

A portion of the earth by analysis gave 2·56 grains of carbon for the whole quantity, and ·24 of nitrogen. These on recapitulation give—

| | Carb. | Hyd. | Oxy. | Nitro. | Ash. | Total. |
|---|---|---|---|---|---|---|
| Carbonic acid | 10·89 | .. | 28·49 | .. | .. | 39·38 |
| Plants | 8·34 | 1·31 | 10·36 | ·84 | 1·45 | 22·3 |
| Roots, husks, &c. | 6·60 | 1·10 | 8·10 | ·70 | 10·70 | 27·2 |
| Earth | 2·56 not determinable. | | | ·24 | | |
| Total | 28·39 | 2·41 | 46·95 | 1·78 | 12·15 | 88·88 |
| Seeds planted | 20·12 | 3·35 | 25·06 | ·61 | ·86 | 50 |
| | +8·27 | −·94 | +21·89 | +1·17 | +11·29 | +38·88 |

shewing an increase of carbon made by the plants of 8·27 grains, equal to 41·1 per cent. with an increase of nitrogen equal to 193 per cent.

The next experiment was made with 5,000 grains of burned plaster of Paris, moistened with distilled water. In twelve hours it became a hard mass, which was broken into fragments and coarse powder. Distilled water was again added to make it of suitable moisture, for the germination of seeds and the growth of plants. These fragments and coarse powder were put into a common flower-pot. On February 27th, 63 seeds of wheat, weighing 50 grains, were planted about half an inch from the surface. The flower-pot was placed on a large dish partially filled with water, which on covering the experiment with a glass globe, content 401 cubic inches, cut off atmospheric communication.

This experiment was kept at a temperature varying from 50 to 60°, and where the sun shone about one-third of the day. These seeds germinated more quickly, and the plants grew more luxuriantly than any other experiment, at that time under observation, with seeds and simple earths. The plants were only watered thrice during the whole period. The following is an account of the carbonic acid which resulted from the experiment:

| | | | | |
|---|---|---|---|---|
| March | 8th, | 7 A.M. | 20·5 | cub. in. of car. acid removed. |
| | 15th, | 7 ,, | 17·5 | do. plants four inches long. |
| | 22nd, | 7 ,, | 5·8 | do. do. 8 in. some with 3 lea. |
| | 29th, | 7 ,, | 5·6 | do. do. cut down. |
| April | 5th, | 7 ,, | 15·5 | do. fresh shoots 4 in. long. |
| | 12th, | 8 ,, | 12·2 | do. plants all flourishing. |
| | 19th, | 7 ,, | 5·4 | do. making little progress. |
| | 26th, | 6 ,, | 8·0 | do. rath. sickly—experiment [broken up. |
| | | | 90·5 | containing 11·83 grs. of carb. |

The first and second cuttings of the plants weighed when dry 18·4 grains, and were constituted of—

| | | |
|---|---|---|
| Carbon | 43·15 | 7·94 |
| Hydrogen | 6·60 | 1·21 |
| Oxygen | 39 24 | 7·22 |
| Nitrogen | 3·21 | ·59 |
| Ashes | 7·80 | 1·44 |
| | 100 | 18·4 |

The roots, parts of stems, and husks, were separated from the plaster of Paris, weighed when dry 26·5 grains, and were constituted of—

| | | |
|---|---|---|
| Carbon | 31·8 | 8·43 |
| Hydrogen | 4·6 | 1·22 |
| Oxygen | 34·0 | 9·46 |
| Nitrogen | 1·2 | ·32 |
| Ashes | 28·4 | 7·07 |
| | 100· | 26·5 |

There is considerable difficulty in getting an average sample for analysis, in order to determine the weight of carbon left by the plants in this moistened earth; and great care should be taken in conducting the analysis, or injury may be sustained from the bursting of the analysing tube.

My best analysis of this part of the experiment, gave for the weight of carbon 3·42 grains in the entire quantity of the earth, and ·15 grains of nitrogen. On a recapitulation of the products we have—

| | Carbon. | Hydr. | Oxygen. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| In the carbonic acid.. | 11·83 | .. | 30·80 | .. | .. | 42·63 |
| „ plants .......... | 7·94 | 1·21 | 7·22 | ·59 | 1·44 | 18·4 |
| „ roots, husks, &c. .. | 8·43 | 1·22 | 9·46 | ·32 | 7·07 | 26·5 |
| „ plaster of Paris .. | 3·42 | not determinable | | ·15 | .. | .. |
| Total........ | 31·62 | 2·43 | 47·48 | 1·06 | 8·51 | 87·53 |
| Seeds planted ...... | 20·12 | 3·35 | 25·06 | ·61 | ·86 | 50· |
| | +11·50 | −·92 | +22·42 | +·45 | +7·65 | 37·53 |

Showing an increase of 11·5 grains of carbon, equivalent to 57·3 per cent., which must have been made by the plants, and an increase of ·45 of a grain of nitrogen, equal to 73·8 per cent., which must either have been taken up from the atmosphere by the plants, or, as will be shown in a subsequent part of these researches, made by the plants.

When a sample of clay and sand, used in making the fourth experiment, was employed in its unburned condition, the increased proportion of carbon made by the plants growing in this unburned mixture, although it contained no carbonaceous matter, was higher than when any of the burned earths were employed.

In a mixture of equal parts of this clay and sand, 63 seeds, weighing 50 grains of the same kind of wheat, were planted, and placed under a shade, whose content was 206 cubic inches; atmospheric communication was cut off by means of water, and the experiment was kept at a temperature varying from 50° to 60°, and in a situation where the sun shone about one-third of the day.

The plants grew luxuriantly, and attained a great height; many of them had five, and some of them six leaves. The volume of carbonic acid proceeding from the plants, was determined in the usual manner on the morning of every fourth day, when the atmosphere was also changed. The entire volume was 118 cubic inches, containing 15·42 grains of carbon. On the thirty-third day of the experiment, the plants were cut off near the earth; when dry, they weighed 23·6 grains. On the forty-sixth day, when the experiment was broken up, they were cut a second time; these weighed, when dry, 5·7 grains, making a total of 29·3, which, on being mixed and analysed, were constituted of—

| | |
|---|---|
| Carbon | 11·31 |
| Hydrogen | 1·71 |
| Oxygen | 13·51 |
| Nitrogen | 1·23 |
| Ashes | 1·54 |
| | 29·3 |

The stems, roots, and husks, when freed from the earth and dried, weighed 30·6 grains, and were constituted of—

| | |
|---|---|
| Carbon | 7·01 |
| Hydrogen | 1·14 |
| Oxygen | 9·08 |
| Nitrogen | ·70 |
| Ashes | 12·67 |
| | 30·6 |

A portion of the earth, on being analysed, gave for the entire quantity 3·32 grains of carbon, and ·3 of nitrogen.

On comparing the carbon and nitrogen resulting from the growing of the seedling wheat plants in this mixture, with the carbon and nitrogen in the seeds planted, we have—

| | Carbon. | Nitrogen. |
|---|---|---|
| Carbonic acid | 15·42 | .. |
| Plants | 11·31 | 1·23 |
| Stems, roots, and husks | 7·01 | ·70 |
| Earth | 3·32 | ·30 |
| Total | 37·06 | 2·23 |
| Seeds planted | 20·12 | ·61 |
| | 16·94 | 1·62 |

Showing an increase of 16·94 grains of carbon, equal to 84 per cent., and an increase of 1·62 grains of nitrogen, equal to 265 per cent.

On taking a review of these six experiments, we perceive there is a variable increase of carbon in the proceeds of the seedling plants, when compared with the weight of carbon in the seeds planted. This increase is—

| When the seeds are planted in | Per Cent. |
|---|---|
| powdered glass | ·4 |
| stone ware | 1·1 |
| burned silicious sand | 24·7 |
| equal parts of burned sand and clay | 41·1 |
| burned plaster of Paris | 57·3 |
| unburned clay and sand | 84·0 |

the earths, in which these seedling plants germinated and grew, were all equally free from carbonaceous matter. With respect to the water, I am not aware that the supply furnished to one experiment, was more favourable to the germination of the seeds or the growth of the plants than to another. The seeds planted were alike in weight and appearance, being selected from the same sample. The atmosphere and temperature under which these experiments were kept was nearly alike. There was a trifling difference in their exposure to the sun's rays, but not such as to materially affect the weight of carbon produced by the plants. The plants of each experiment were *first* cut, when their growth flagged, and their lower leaves began to decay. They were cut the *second* time, when they appeared to have lost their vegetating power.

These six experiments may be regarded as having had equal facilities for the germination of the seeds and the growth of the seedling plants; the different earths in which they grew excepted.

With all these similarities, we find the weight of the increase of carbon, when compared with that originally contained in the seeds, is very dissimilar, varying from ·4 to 84 per cent. To what is this increase of carbon to be ascribed?—and what gives rise to this difference in this increase?

The increased weight of carbon cannot be ascribed to the earths alone; for calcined earths may be kept for many years, in a proper state of moisture and temperature for favouring vegetation, and surrounded by the common atmosphere, and no carbon be made, if no seeds are deposited in it.

We have seen (page 120) that when seedling plants grow where no earth is present, there is a loss of carbon, varying according to the circumstances under which they are placed: the weight of carbon produced, being no measure of that which was originally contained in the materials subjected to experiment. The inference deducible from all these experiments is, that the making of this increased weight of carbon, is due more especially to the plants; and that plants in the making of this body, are influenced in their functional operations by the earths which surround them; for the earth alone does not make carbon, neither do the seedling plants when allowed to perform their vegetative functions without the earths, increase their quantity of carbon. But when the seeds are deposited in these earths, and allowed to germinate and grow, there is an increase of carbon.

We now see that carbon is a vegetable product made by plants growing under certain influences; and that we have a process in nature by which a provision may be made for that loss of this body sustained by other natural processes.

It is also to be observed, that in the last six experiments, (with the exception of the one made with unburned clay and sand,) when we omit from the calculation the carbon in the carbonic acid removed from the atmosphere, there is a loss of carbon. This loss when the seeds were planted in—

| | | |
|---|---|---|
| Powdered stoneware was | 41·3 | per cent. |
| Burned silicious sand was | 13·0 | „ |
| Burned clay and sand in equal parts | 12·5 | „ |
| Burned plaster of Paris was | 1·1 | „ |
| And a gain of carbon when the seeds were planted in unburned clay and sand, of | 7·6 | „ |

The products resulting from other experiments teach us; that if the atmosphere in these had been generally changed in the evening instead of the morning, the weight of carbon in the plants, roots, husks, and the earth, &c., would have been greater; but supposing this plan had been adopted, the additional increase in the plants, &c., would not have been equal to that which disappears from the atmosphere. From these we conclude, that when wheat seeds are planted in any of the burned earths, the plants which they yield, while they may contain more water and nitrogen, contain less in weight of carbon than was originally in the seeds; but when they are planted in unburned clay and sand, the weight of carbon is also increased.

## THE QUANTITY OF CARBON PRODUCED BY PLANTS VARIES WITH THE QUANTITY OF EARTH IN WHICH THEY GROW.

That the quantity of carbon produced by plants during their growth varies with the quantity of earth in which they grow, irrespective of the organic matter contained in the earth, is evidenced by the three following experiments. The earths employed were free from organic matter, and formed a mixture constituted of equal weights of clay and sand. This mixture was first acted upon by dilute sulphuric acid; afterwards repeatedly washed with water, and dried. To ensure entire freedom from organic matter, these dry earths were exposed to a red heat in a crucible for more than an hour, and frequently stirred during the time.

Three portions of these prepared earths, represented by Nos. 1, 2, 3, weighing respectively 1,500, 3,500, and 7,000 grains, were placed in flower-pots all of the same size. The earth in No. 1 lay about one inch deep, in No. 2 about two inches, in No. 3 four inches in depth. Sixty-three seeds, weighing 50 grains of the red wheat, were planted in each of these flower-pots, half an inch from the surface of these earths. Distilled water was added to bring the earths to an equal, and to such a state of moisture, as to favour the early germination of the seeds.

Each pot was placed in a saucer standing upon a plate filled with water; atmospheric communication was cut off by covering each experiment with a glass shade. The content of the glass shade for No. 1, was 200; for No. 2, 206; and for No. 3, 218 cubic inches. The experiments were equally exposed to the sun's rays, at a temperature varying from 50° to 70°

On the seventh day of the experiment, young shoots from each seed were visible above the earth. On the fourteenth day, the young plants were two inches in height. The atmosphere of each experiment was examined and changed on the morning of every seventh day, when fresh water was supplied to the plants.

There was scarcely an appreciable difference in the appearance of the plants in the three experiments during the first thirty days. After which period, those in No. 1 made little progress in growth, and some of the lower leaves began to turn brown. On the forty-fifth day, the stems of the plants in No. 1 were more slender than those in the other two. At this time the plants in each experiment were cut. The stems of Nos. 2 and 3, after being cut, made fresh leaves; while those in No. 1 scarcely made any progress in growth. On the fifty-fourth day, the experiments were finally examined. The plants, stems, roots, and husks were carefully separated from the earth, were dried, and analyzed: portions of the earths of each experiment were also analyzed. The following is an account of the carbon in each:—

| | No. 1. | No. 2. | No. 3. |
|---|---|---|---|
| In the carbonic acid .. | 6·60 | 8·24 | 8·44 |
| „ plants ........ | 6·01 | 6·42 | 6·74 |
| „ roots and husks | 7·00 | 8·02 | 9·37 |
| „ earth.......... | 1·80 | 3·47 | 3·22 |
| Total ...... | 21·41 | 26·15 | 27·77 |
| „ seeds planted .. | 20·12 | 20·12 | 20·12 |
| Increase .... | 1·29 | 6·03 | 7·65 |

shewing an increase of carbon in the experiments when—

| | |
|---|---|
| 1,500 grains of earth was employed.. | 6·4 per cent. |
| 3,500 „ | .. 30·0 „ |
| 7,000 „ | .. 37·8 „ |

On leaving out of the calculation the portion of carbon in the carbonic acid resulting from the experiments, we have a deficiency of carbon in

| | |
|---|---|
| No. 1.......... | 26·4 per cent. |
| No. 2.......... | 11·2 „ |
| No. 3.......... | 3·5 „ |

When 20 grains (by weight) of turnip, and the same quantity of rape seeds, were substituted for the wheat seeds, in similar quantities of burnt clay and sand, there was not the same variation in the proportions of carbon made by the plants. These gave an increase of carbon in

| | Turnip. | Rape. |
|---|---|---|
| No. 1......... | 33·2 | 29·8 per cent. |
| No. 2 ........ | 38·4 | 34·5 „ |
| No. 3 ........ | 40·4 | 36·0 „ |

In these experiments about one half of the turnip, and two-thirds of the rape seed, germinated. The temperature at which they were kept varied from 50° to 65°. In Nos. 2 and 3 of the turnip, and No. 3 of the rape seed experiments, the carbon in the carbonic acid, resulting from the experiments, was from 85 to 95 per cent. of that contained in the seeds planted. Allowing for the carbon in the carbonic acid, the deficiency of carbon was much greater than in the experiments with wheat seeds.

When pease were made the subject of experiment, in similarly prepared earths, and kept at a temperature not exceeding 56°, the carbonic acid removed every third day contained more carbon than was comprised in the seeds planted. On calculating for the carbon in all the products of the experiment, there was an increase of 60 per cent. Allowing for the carbon in the carbonic acid, there was a decrease of 58 per cent.

From these and other experiments, made with different kinds of seeds, I draw the following conclusions:—First, that the power which plants possess of making carbon, is influenced by the quantity of earth in which the seeds are planted. Secondly, that in order to obtain the strongest plants, the seeds should be placed in earth whose depth is not less than from three to four inches. Thirdly, that the increase of carbon in plants, bears a direct proportion to that contained in the carbonic acid given off.

## THE QUANTITY OF CARBON MADE BY PLANTS IS INFLUENCED BY TEMPERATURE.

When the same kind of seeds as those mentioned under the last head, were planted in mixtures of sand and clay, in the months of May and June, the quantity of carbon included in the young plants, roots, and husks produced, was greater than when the experiments were conducted at a temperature, and season less favourable to their growth.

The first experiment was made with 50 grains (62 seeds) of red wheat, planted in a mixture of 1 lb. of equal parts of the prepared clay and sand. Atmospheric communication was cut off by mercury and water. It was under experiment fifty days, during which period the atmosphere was examined, and changed eight times. This experiment gave the following results in

| | Car. | Hyd. | Oxy. | Nitr. | Ash. | Total. |
|---|---|---|---|---|---|---|
| The carbonic acid ...... | 8·06 | .. | .. | .. | .. | .. |
| Leaves & stems of plants | 7·69 | 1·17 | 9·11 | ·62 | 1·21 | 19·8 |
| Roots, husks, &c. ...... | 9·79 | 1·50 | 11·54 | ·66 | 6·71 | 30·2 |
| Earth ................ | 3·44 | not determinable | | ·24 | .. | .. |
| Total.......... | 28·98 | .. | .. | 1·52 | .. | .. |
| In the seeds............ | 20·12 | 3·35 | 25·06 | ·61 | ·86 | ·50 |
| Increase........ | 8·86 | .. | .. | ·91 | .. | .. |

Increase of carbon, exclusive of that in the carbonic acid, 4 per cent.; increase of carbon, inclusive of that in the carbonic acid, 44 per cent.

The following experiments were made in the month of May, with the same weight and number of wheat seeds. The atmosphere, without being examined, was changed every third day.

No. 1. One-third prepared clay, and two-thirds sand. Atmosphere cut off by mercury and water. Under experiment thirty-seven days.

| | Car. | Hyd. | Oxy. | Nitr. | Ash. | Total |
|---|---|---|---|---|---|---|
| Plants .......... | 8·49 | 1·23 | 8·51 | ·56 | 1·31 | 20·1 |
| Roots, &c. ........ | 9·20 | 1·51 | 10·77 | ·53 | 10·67 | 32·7 |
| Earth ........... | 2·62 | not determinable | | ·13 | .. | .. |
| Total ...... | 20·31 | .. | .. | 1·22 | .. | .. |
| Seeds ............ | 20·12 | 3·35 | 25·06 | ·61 | ·86 | 50· |
| Increase .... | 0·19 | .. | .. | ·61 | .. | .. |

Increase of carbon, without that in the carbonic acid, ·95 per cent.

No. 2. Equal parts of the clay and sand. Atmosphere cut off by mercury and water. Under experiment forty-eight days.

| | Car. | Hyd. | Oxy. | Nitr. | Ash. | Total. |
|---|---|---|---|---|---|---|
| Plants ............ | 10·46 | 1·44 | 9·00 | 1·15 | 3·35 | 25·4 |
| Roots, &c.......... | 7·27 | 1·09 | 7·42 | ·48 | 6·44 | 22·7 |
| Earth ............ | 4·64 | .. | .. | ·28 | .. | .. |
| Total........ | 22·37 | .. | .. | 1·91 | .. | .. |
| Seeds ............ | 20·12 | 3·35 | 25·06 | ·61 | ·86 | 50· |
| Increase .... | 2·25 | .. | .. | 1·30 | .. | .. |

Increase of carbon, without that in the carbonic acid, 11·3 per cent.

No. 3. Two-thirds of the clay and one-third sand. Atmosphere cut off by water only. Under experiment sixty-four days.

| | Car. | Hyd. | Oxy. | Nitr. | Ash. | Total. |
|---|---|---|---|---|---|---|
| Plants ............ | 10·04 | 1·49 | 9·95 | ·51 | 1·81 | 23·8 |
| Roots, &c.......... | 11·07 | 1·83 | 12·02 | ·65 | 4·03 | 29·6 |
| Earth ............ | 3·01 | .. | .. | ·21 | .. | .. |
| Total........ | 24·12 | .. | .. | 1·37 | .. | .. |
| Seeds ............ | 20·12 | 3·35 | 25·06 | ·61 | ·86 | 50· |
| Increase .... | 4· | .. | .. | ·76 | .. | .. |

Increase of carbon, independently of that in the carbonic acid, 19·8 per cent.

When twenty grains, by weight, of turnip seeds was planted in one lb. of equal parts of prepared clay and sand, on the 14th of May, and under experiment twenty-eight days, atmospheric communication being cut off by mercury and water, the increase of carbon, when compared with that in the seeds, was—

Exclusive of that in the carb. acid 4·8 per cent.
Inclusive ditto ditto 62·4 ,,

And from an experiment made with the same weight of rape seed, planted at the same time, the increase was—

| | | |
|---|---|---|
| Exclusive of the carbon in the carbonic acid .............. | 1·8 | per cent. |
| Inclusive of that in the carb. acid | 48·7 | „ |

When thirty early peas, weighing 100 grains, were planted in similar mixtures, in the month of May,—

| | | |
|---|---|---|
| The increase of carbon, exclusive of that in the carbonic acid, was | 7·8 | per cent. |
| Inclusive of that in the carb. acid | 72·0 | „ |

From the various experiments I have made, at different seasons of the year, and among which may be enumerated the above, and those under the preceding head, I am disposed to infer that temperature, and consequently climate, has considerable influence over the power inherent in plants, for making carbon and retaining it in the vegetable structure; and that it is temperature, as well as solar influence, which favors the making of this body. For as much carbon, including that in the carbonic acid, was yielded by seedling plants, their roots and husks, and the earth, when they had been kept in a hot-house, at a moderate summer-heat, during the months of January and February, as those seedling plants which had grown in June and July.

### THE QUANTITY OF CARBON MADE BY PLANTS IS INFLUENCED BY MIASM.

When plants grow in earth, or in an atmosphere impregnated with vapours proceeding from decomposing animal or vegetable matter, their power of making carbon is very considerably increased. The following experiments are given in corroboration of this feature in vegetable physiology. The three first to be described, were each made with 27 of the largest seeds of the red wheat, weighing 25 grains. These were placed in china egg-cups, holding clean rain water, and kept at a temperature not exceeding 60°, for 40 hours. The water was then drained off, and each cup was placed under a tall glass jar. The content of jar No. 1, being 70; of No. 2, 98; and of No. 4, 143 cubic inches. Under jar No. 2, was placed a narrow-necked one-ounce bottle, holding 200 grains of dilute liquor, obtained by washing decayed sea-weed, and which contained ·2 per cent. of its weight of carbon. Atmospheric communication was cut off by water.

These experiments stood in a hot-house, kept at a temperature varying from 60 to 75°, during the month of March. The seeds in all the experiments germinated on the third day. From that time the plants in No. 2, made much more progress in growth; and, upon examination every fifth day, contained more carbonic acid than either Nos. 1 or 3.

On the twenty-fifth day, the experiments were finally examined: two days previous to this, many of the leaves in each experiment had begun to fade. The putrid liquor had lost four grains in weight, which would not contain ·02 of a grain of carbon.

The carbonic acid removed at each examination, was, on the—

| | No. 1. | No. 2. | No. 3. | |
|---|---|---|---|---|
| 5th day, from | 2·3 | 3·9 | 2·6 | cub. inches. |
| 10th „ | 4·6 | 5·8 | 5·3 | „ |
| 15th „ | 3·6 | 6·0 | 4·3 | „ |
| 20th „ | 4·0 | 3·1 | 4·4 | „ |
| 25th „ | 5·2 | 5·4 | 6·6 | „ |
| Total…… | 19·7 | 24·2 | 23·2 | |
| In the atmosphere when enclosed .. | 3·5 | 4·7 | 7·2 | „ |
| Given off by the plants .. | 16·2 | 19·5 | 16·0 | „ |
| Containing | 2·12 | 2·54 | 2·09 | grs. of carb. |

The weight of the stems, leaves, and roots, when dried at a temperature not exceeding 100, was for—

No. 1, 9·78 grs., and contained 4·11 grs. of carb.
„ 2, 11·76 „ „ 4·90 „
„ 3, 11·28 „ „ 4·73 „

The weight of the husks, and the flower which some of them contained, was for—

No. 1, 6·24 grs., and comprised 2·56 grs. of carb.
„ 2, 6·33 „ „ 2·69 „
„ 3, 5·52 „ „ 2·24 „

These on a recapitulation gave for the weight of the carbon in—

| | No. 1. | No. 2. | No. 3. | |
|---|---|---|---|---|
| The carbonic acid .. | 2·12 | 2·54 | 2·09 | grs. |
| The stems, leaves, and roots …… | 4·11 | 4·90 | 4·73 | „ |
| The husks …….. | 2·56 | 2·69 | 2·24 | „ |
| Total …… | 8·79 | 10·13 | 9·06 | „ |
| The seeds planted.. | 10·06 | 10·06 | 10·06 | „ |
| Difference | −1·27 | +·07 | −1· | |

In the experiments where no stimulating liquor was present, we have a loss of carbon, in the one conducted under the smallest jar, of 1·27 grains, equal to 12·5 per cent.; and in that under the largest jar, of 1· grain, equal to nearly 10 per cent. In the experiment where the atmosphere was impregnated with miasm, proceeding from the decayed sea-weed liquor, we have the plants growing more luxuriantly, giving off more carbonic acid than either of those above-mentioned, and an increase of carbon, when compared with that in the seeds planted.

The results of these experiments confirm those obtained from others already mentioned, viz., that when seedling plants grow without earthy matter, there is a considerable loss of carbon, when that which is passed off to the surrounding atmosphere is not taken into account. They also teach us that noxious vapour, containing an inappreciable weight of carbon, when confined within the atmosphere in which plants grow, stimulates them in the performance of their functions; a property which it likewise appears to possess when the seeds are planted in earth.

The next experiments were made with equal parts by weight, of sand and clay, prepared by dilute sulphuric acid and burning (see page 64). Two flower-pots were each nearly filled with one lb. of this mixture, which was moistened with distilled water. Sixty-two seeds of the wheat, weighing 50 grains, were planted about half an inch from the surface of the earth, in each flower-pot.

A tube, half an inch in diameter, was filled within two inches from the top, with liquid obtained from decayed turnip leaves, and placed in the centre of the earth in No. 1, so as to stand three inches above the top of the flower-pot. This liquor contained

1·7 per cent. of its weight of carbon. Contact with the surrounding atmosphere was cut off by glass shades: the content of No. 1, was 223, and that of No. 2, 218 cubic inches. The only difference in the two experiments was, that No. 1. included the tube containing the putrid liquid.

The two experiments stood, side-by-side, in a laboratory, not artificially heated, and where the sun shone from 1 P.M. till sunset. They were fitted up in February, and continued until the end of April. The plants in No. 1 made more progress in growth than No. 2. The atmosphere in each was examined and changed on the morning of every 7th day.

The plants in No. 2 appeared to make little progress in growth during the eighth week, and on the ninth this experiment was broken up, and finally examined. The plants in No. 1 retained their vegetative properties for ten weeks, when the experiment was discontinued. The tube containing the putrid liquor was now removed, and upon being weighed was found to have lost eight grains. This small loss in weight, which would not contain more than ·13 of of a grain of carbon, kept the atmosphere within the shade charged with miasm during the ten weeks.

There was removed from No. 1, 102 cub. inches. of

| | Carb. | Hydro. | Oxy. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| Carbonic acid containing | 13·34 | | | | | |
| Leaves and stems ...... | 7·98 | 1·11 | 7·35 | ·66 | 1·40 | 18 5. |
| Roots, husks, &c. ...... | 8·22 | 1·12 | 8·67 | ·34 | 6·45 | 24·8 |
| Earth ................ | 3·34 | .. | .. | ·16 | | |
| Total........ | 32·88 | ............. | | 1·16 | | |
| Seeds ..........20·12<br>Putrid liquor.... ·13 | 20·25 | 3·35 | 25·06 | ·61 | ·86 | 50·13 |
| Difference..... | 12·63 | .............. | | ·55 | | |

being an increase of 12·63 grains of carbon, equivalent to 62·2 per cent.

There was removed from No. 2, 62 cubic inches of—

| | Carb. | Hydro. | Oxy. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| Carb. acid containing | 8·11 | | | | | |
| Plants ............ | 6·64 | ·83 | 6·80 | ·42 | 1·47 | 16·1 |
| Roots, husks, &c..... | 9·30 | 1·17 | 9·32 | ·44 | 4·17 | 24·4 |
| Earth ............. | 3·42 | .. | .. | ·20 | | |
| | 27·47 | | | 1·06 | | |
| The seeds.... | 20·12 | | | ·61 | | |
| Difference ... | 7·35 | | | ·45 | | |

being an increase of carbon equal to 36 per cent.

On comparing the quantity of carbon made by the seedling plants in these two experiments, we find that the increased quantity made under the influence of miasm, proceeding from the turnip liquid, was equal to 26 per cent.

These experiments are examples of the exceptions alluded to in page 123. The seedling plants which grew in the atmosphere charged with miasm, grew more luxuriantly than those which vegetated in the common atmosphere. The stimulating influence of the miasm in the atmosphere in which the plants grow, appears not only to favour the making of, and assimilating carbon by the vegetable, but also to the formation of carbonic acid, which is more fully evidenced in the ensuing experiment wherein putrid animal matter was used.

In this experiment we have an example of the very powerful influence produced upon the growth of seedling plants, by liquid obtained by the slow distillation of lean beef, which had been under putrefaction for fourteen months. This liquid, on being received from the retort, was put into a thin glass vessel hermetically sealed, and hung up where the sun's rays fell upon it more than half the day. In less than two months it began to darken in colour; and in less than six months it became black and transparent. Its specific gravity was 1002·2 at 60°, and, according to the best analysis I could make, it contained ·23 per cent. of its weight of carbon.

A small flower-pot, No. 1, was nearly filled with half a pound of earth, containing no carbonaceous matter, and constituted of one-sixth burned clay, and five-sixths burned sand. This was moistened with distilled water and 500 grains of the black liquid. Sixty-three seeds of the red wheat, weighing 50 grains, were planted in this moistened earth in the month of December, and placed where the temperature varied from 60° to 70°.

The seeds in No. 1 not germinating so early as those in No. 2, made at the same time with a similar mixture of earth moistened with water only, were examined on the seventh day of the experiment, when the husks were found to be quite black. Strong rootlets were making their appearance in many of the seeds, but, generally speaking, their germination was a few days later than those in the other experiment. On the 28th of Dec. these two experiments were placed in a vinery, which from this time was put under artificial heat. The lowest temperature at which it was kept was gradually increased from 50° to 65°. This vinery did not include a forcing-pit, or any other mixture whose decomposition gave off carbonic acid gas.

In No. 1, which contained the putrid liquid, 58 of the seeds, and in No. 2, 61 of the seeds germinated and grew. During the third and fourth weeks, the experiments were occasionally covered with glass shades. At each examination the carbonic acid in No. 1 was in higher proportion than that in No. 2.

For the first three weeks the plants in No. 2, made the greatest progress in growth; but those in No. 1, which always assumed a healthy appearance, and were darker in colour, were the first to put forth their third leaf, and from the fourth week continued to grow most luxuriantly, the atmosphere of the experiment being impregnated with the odour of the putrid liquor during the growth of the plants. The stems were strong, and on the eighth week supported six and seven leaves. The stems of the plants in No. 2, were comparatively weak, and never supported more than three leaves. They were twice cut the first eight weeks, after which they made no progress in growth. The experiment was then discontinued, and the different parts on examination yielded when dry—

| | | | |
|---|---|---|---|
| Stems and leaves | 16·6 grs. | which contained | 6·62 grs. of carbon. |
| Roots, husks, &c. | 23·8 | „ „ | 8·36 „ |
| Earth | | | 3·56 „ |
| | | Total | 18·54 |
| | | The seeds planted | 20·12 |
| | | Deficiency | 1·58 |

In this experiment we have a loss of 1·58 grains of carbon when compared with that in the seeds planted, without taking into account that in the the carbonic acid imparted to the atmosphere. This loss is equivalent to 7·8 per cent.

The small flower-pot (No. 1,) was, on the ninth week so crowded with plants, that thirty-six of the weakest were cut down; their weight when dry was ·14 grains. Fresh shoots made their appearance on the following day, and in fifteen days they were again cut; the dead leaves were also gathered, and when mixed with the former cutting weighed 52·3 grain, and were constituted of—

| | | |
|---|---|---|
| Carbon | 40·8 | 21·33 |
| Hydrogen | 5·8 | 3·03 |
| Oxygen | 42·9 | 22·43 |
| Nitrogen | 4·3 | 2·25 |
| Ashes | 6·2 | 3·26 |
| Total | 100· | 52·3 |

When the vinery was kept at a temperature seldom exceeding 70° the plants all grew luxuriantly; as the bottom leaves decayed, fresh leaves made their appearance. At the latter end of the month of March and at the beginning of April, when the vinery was raised from five to ten degrees, the increase of temperature appeared at first to quicken the growth of the plants; but after it had continued about ten days, the leaves on all the stems began to turn yellow, and on the 6th of April every leaf and stem was swarming with small green insects.

At this time there were eighteen strong plants apparently ready for earing, but upon examination no trace of an ear could be discovered. They were then cut down and dried, and when analysed, the eighteen stems, together with their leaves, weighed 62·8 grains, and were constituted of—

| | |
|---|---|
| Carbon | 25 42 |
| Hydrogen | 3·52 |
| Oxygen | 27·18 |
| Nitrogen | 2·61 |
| Ashes | 4·07 |
| | 62·8 |

The roots and husks, on being removed from the earth and dried, weighed 54·4 grains, and were constituted of

| | |
|---|---|
| Carbon | 18·2 |
| Hydrogen | 2·5 |
| Oxygen | 19·8 |
| Nitrogen | 1·6 |
| Ashes | 12·3 |
| | 54·4 |

A portion of the earth on being analysed, gave for the whole quantity 6·4 grains of carbon.

On comparing the weight of the carbon resulting from this experiment with that in the seeds planted, and what was contained in the putrid liquor, we have in

| | | | |
|---|---|---|---|
| Those plants first analysed | | 21·33 | grains. |
| Those plants last do. | | 25·42 | ,, |
| The roots and husks | | 18·20 | ,, |
| The earth | | 6·40 | ,, |
| Total | | 71·35 | grains. |
| The seeds planted | 20·12 | 22·27 | |
| The putrid liquor | 1·15 | | |
| Increase | | 59·08 | eq. to 264 per cent. |

On comparing the proceeds of this experiment with those of No. 2, which was similarly conducted, except that it contained no putrid liquid, we have the quantity of carbon made, and assimilated by the plants growing under the influence of this liquid equal to 272 per cent. If the carbonic acid given off by these plants had been collected, and its carbon determined, and added to that above mentioned, it is probable that the whole quantity would have been from five to six times that contained in the seeds planted.

Thus, in those experiments which were conducted without the presence of earthy matter, the increase of carbon gained by the addition of the miasm of decayed sea-weed to the atmosphere was from 10 to 13 per cent.—when the seeds were planted in earth containing no carbonaceous matter. The increase of carbon by the addition of miasm of the decayed turnip liquid to the atmosphere was 26 per cent.

In the experiment in which the seeds were planted in earth, partly moistened with liquid distilled from putrid lean beef, the weight of carbon, without taking into account that in the carbonic acid imparted to the atmosphere, was more than three times that which resulted from the experiments kept under equal circumstances, the putrid liquid excepted; and by taking into account the carbon in the carbonic acid given off, the weight of carbon made by the plants through the influence of miasm, would in all probability be six times that in the seeds planted.

The carbon which disappeared from the different putrid liquids was, when the carbon in the carbonic acid was included:—

| | |
|---|---|
| In the experiment without earth and the miasm from decayed sea-weed ...... | $\frac{1}{50}$ part of that made by its influence. |
| In the one with earth and the miasm from decayed turnip liquid ................ | $\frac{1}{41}$ part of that made by its influence. |
| In the experiment the liquid from decayed beef being mixed with the earth .... | $\frac{1}{160}$ part of that made by its influence. |

And on leaving out of the calculation, the carbonic acid given off to the surrounding air during the growth of the plants in the last-mentioned experiment, the carbon which disappeared from the putrid liquid was $\frac{1}{51}$ part of the carbon added to the plants by its influence.

It is evident from these experiments, that plants are influenced in their functional operations by miasm, whether it be present in the atmosphere or in contact with the earth in which the plants grow; and that the quantity of carbon which disappears from the putrid matter thus circumstanced, bears an almost inappreciable proportion to that made by the plants owing to its influence; and likewise, that different bodies exert an influence upon the growth of the plants varying with the *kind* of putrid liquid, the miasm proceeding from animal matter being more powerful in its influence, than that from putrid vegetable substances.

There can be no doubt, that a part of the beneficial effect produced by the *top dressing* of pasture land, is owing to the miasm formed during the decomposition of the manure. The miasm given off during the decomposition of the upper strata of manure, stimulates the plants, in the immediate neighbourhood in which it is, to grow quicker, and increase in carbon. By this decomposition, a portion of matter soluble in cold water is formed, which, on the falling of rain, is immediately dissolved and brought in contact with the roots. This dissolved matter, being also in a favourable condition for forming miasm at ordinary temperatures, is gradually given off, and exerts its influence, as well upon the roots, as upon the stems and leaves, of the plants immediately in contact with the earth. The abundant crops of grass, and other plants grown on burial grounds, and on lands to which much animal matter has been carried, and deposited at considerable depths, may in all probability be properly ascribed to the influence of miasm, rather than to the quantity of carbon in the carbonic acid given off by the decomposition of such matter; for we find that when organic matter, and especially that of animals, is in that state of decomposition in which it is most valuable as a manure, the miasm is most abundant; but the volume of carbonic acid is comparatively small.

The beneficial influence of miasm upon the growth of plants, is no less evidenced by experiment during their growth, than its removal by them from the atmosphere in which they are confined. Thus vegetation is a means of removing unwholesome effluvia from the atmosphere.

The influence of miasm on the growth of plants, and their power of making carbon, is also evidenced, when we compare the results of the last-mentioned experiments, with those wherein other substances, which are well known to favour the growth of plants, were mixed with the earths employed.

Two days previously to making the following experiments, separate portions of different kinds of organic matter were mixed with rain water, and the mixture during the first six hours frequently stirred. On the second day, the clear liquor was poured off, and its sp. gr. determined; the quantity of organic matter held in solution was calculated for after the rate of ·24 per cent. by weight, for each degree of sp. gr., water being 1000 at 60°.

The earths employed were not, previously to planting the seeds, either burned or acted upon by dilute acids. The flower-pots, into which the earths were put, were all as nearly alike as possible with regard to shape, size, and bore-hole, which latter is of great consequence, both as regards the air which it admits, and the water which it allows to escape.

The weight of the dry sand and clay used for each experiment was 3,000 grains, in which 50 grains by weight (63 seeds) of wheat were planted, about half an inch from the surface of the earth, on the 2nd of February.

To each experiment was first added as much of the solutions above-mentioned, as comprised three grains of each kind of organic matter; rain water was then added, to sufficiently moisten the earth. For the first four days, as much water was placed in the saucer in which each flower-pot stood, as kept the earth in a proper state of moisture for favouring the germination of the seeds.

The object in thus mixing the organic matter with the earth was, that its influence upon the growth of the plants might be exerted, in its natural state, before it had undergone any decomposition. This object was so far attained as the nature of such experiments admits of, for it is impossible to prevent the decomposition of these bodies when in solution, and kept at a temperature favourable for chemical change, and exposed to the influence of the atmosphere.

The experiments, when thus prepared, were arranged side by side in a hot-house, kept at a temperature varying from 65° to 75°.

On the fourth day, all the seeds, with very few exceptions, had germinated. The flower-pots were then removed from the saucers, and placed on two narrow boards, which were about an inch apart; air was thus freely admitted to the roots of the plants through the aperture at the bottom of each flower-pot.

From this period to the conclusion of the experiments, the plants were supplied with rain water. Nos. 16, and 18, were occasionally kept for four days together covered with a glass shade. Atmospheric communication was cut off by water, and the carbonic acid given off by each of these two experiments was registered.

The plants in all the experiments grew luxuriantly: on nearly all of them there were three leaves on the 19th of February; and on the 26th, on many, there were four leaves. On the 3rd of March, the bottom leaves on several of the plants began to fade; they were at this time all cut off, about half an inch from the earth, and dried. In two days fresh shoots made their appearance, which continued to grow till the 4th of April, when the plants generally appeared to be in a decaying state: they were then again cut down. The second cuttings were dried, and mixed with the others. The flower-pots were emptied of their contents, which were dried on the flue of the hot-house; the roots and husks were then carefully separated from the earth. The proceeds of the two experiments, in which the same kind of organic matter was used, were mixed and analyzed, as well as the earths in which the plants grew. The weight in grains of the plants, &c. in each of these experiments, together with the weight of carbon resulting from each two, which were alike, are given in the following table:—

| | Number | Weight of | | | Total. | Carbon per cent. when compared with that in the seeds planted. | |
|---|---|---|---|---|---|---|---|
| | | Dry Plants. | Dry Roots and Husks. | Carb. in the experiments alike. | | Incr. | Dec. |
| Excrement from the horse fed principally upon meadow hay | 1 | 37·2 | 23·0 | 43·1 | 47·0 | 16·8 | .. |
| | 2 | 36·0 | 21·2 | | | | |
| The two portions of earth | .. | .. | .. | 3·9 | | | |
| Excrement from the cow fed upon the same kind of hay | 3 | 33·5 | 21·5 | 42·5 | 46·3 | 15·1 | .. |
| | 4 | 36·8 | 20·4 | | | | |
| The two portions of earth | .. | .. | .. | 3·8 | | | |
| Human excrement | 5 | 36·3 | 18·6 | 44·0 | 48·2 | 19·1 | .. |
| | 6 | 40·5 | 23·8 | | | | |
| The two portions of earth | .. | .. | .. | 4·2 | | | |
| Human urine | 7 | 39·8 | 21·3 | 44·6 | 49·1 | 22·0 | .. |
| | 8 | 40·6 | 20·2 | | | | |
| The two portions of earth | .. | .. | .. | 4·5 | | | |
| Excrement of sheep pastured in a low meadow | 9 | 40·2 | 24·2 | 45·5 | 50·5 | 25·2 | .. |
| | 10 | 37·4 | 23·3 | | | | |
| The two portions of earth | .. | .. | .. | 5·0 | | | |
| Excrement of pigs fed principally upon distillers' grains | 11 | 40·3 | 24·6 | 49·4 | 54·7 | 35·9 | .. |
| | 12 | 41·4 | 25·7 | | | | |
| The two portions of earth | .. | .. | .. | 5·3 | | | |
| Excrement of poultry | 13 | 38·8 | 23·2 | 50·2 | 56·0 | 41·5 | .. |
| | 14 | 46·3 | 27·6 | | | | |
| The two portions of earth | .. | .. | .. | 5·8 | | | |
| Decomposed stable manure | 15 | 40·3 | 25·4 | 52·9 | 58·9 | 46·3 | .. |
| | 16 | 47·6 | 28·6 | | | | |
| The two portions of earth | .. | .. | .. | 6·0 | | | |
| Sea weed which had been under decomposition for twelve months | 17 | 38·3 | 23·3 | 48·7 | 54·4 | 35·2 | .. |
| | 18 | 43·4 | 26·7 | | | | |
| The two portions of earth | .. | .. | .. | 5·7 | | | |
| Cabbage leaves which were in a highly decomposed state | 19 | 36·7 | 23·8 | 44·9 | 49·2 | 32·2 | .. |
| | 20 | 36·5 | 24·3 | | | | |
| The two portions of earth | .. | .. | .. | 4·3 | | | |
| Supplied with water only | 21 | 36·0 | 16·4 | 37·1 | 40·5 | ·6 | .. |
| | 22 | 32·8 | 16·1 | | | | |
| The two portions of earth | .. | .. | .. | 3·4 | | | |
| Supplied with water only, and in pots, where the earth lay about two-thirds the depth | 23 | 32·7 | 16·0 | 35·2 | 38·5 | .. | 4·3 |
| | 24 | 30·6 | 15·8 | | | | |
| The two portions of earth | .. | .. | .. | 3·3 | | | |

If we wish to make a calculation for the whole quantity of carbon which proceeded from these experiments, that in the carbonic acid given off by the plants may be computed at from 70 to 80 per cent. of that shewn to be in the plants and the roots.

The first feature which arrests our attention in these experiments, which were conducted alike, is the difference in the weight of the dry plants produced. This difference is, in Nos. 1 and 2, 3 per cent.; between Nos. 3 and 4, nearly 10 per cent; Nos. 5 and 6, nearly 11 per cent.; between 13 and 14, nearly 20 per cent.; &c. These dissimilarities show that we cannot obtain uniform results when living plants are the operating agents; and lead us to expect great differences in the weight of the annual produce of land, even when it is kept under the direction of the most experienced agriculturist. But as in practical agriculture, so in vegetable chemistry, it is only by steady perseverance, successively trying every variety of method and combination, that practical knowledge or scientific principles can be attained.

There are two parts of these experiments, which when taken in connection with the others, deservedly claim the attention of the agriculturist. These are the roots left in the ground by the plants, and the carbon obtained from the earth by analysis. On taking the greatest care, and on making the best comparisons, I always find in experiments of this kind that the roots of similar plants bear a direct proportion to the weight of the leaves, stems, &c., and the same applies to the quantity of carbon left in the earth in which the plants have grown. Thus, in the examples before us, with very few exceptions, we have the greatest weight of roots in those experiments which afforded the greatest weight of plants.

The dry leaves and stems when compared with the dry roots, &c. were in

| | |
|---|---|
| No. 2 | 36·0 to 21·2 |
| 6 | 40·5 to 23·8 |
| 12 | 41·4 to 25·7 |
| 16 | 47·6 to 28·6 |

The weight of the carbon in the plants, roots, &c. and that in the earths where they grew is

| | In the plants, roots, &c. | In the earth. |
|---|---|---|
| Nos. 1 and 2 | 43·1 | 3·9 |
| 5 and 6 | 44·0 | 4·2 |
| 11 and 12 | 49·4 | 5·3 |
| 15 and 16 | 52·9 | 6·0 |
| 21 and 22 | 37·1 | 3.4 |

We find the land, therefore, which yields the largest produce of any kind of plants (whose roots are left in the soil) retains the most organic matter, which, on undergoing decomposition, will promote the growth of other plants.

These experiments afford valuable information as to the influence of different organic bodies on the growth of the wheat plant.

On taking the proceeds of these experiments by two and two, as they were made alike, and comparing them, we find a considerable difference; a part of which we may safely ascribe to the effect produced by the different kinds of organic matter used. Thus, for example, we have the increase in the weight of the carbon when compared with that in the seeds planted.

| | | |
|---|---|---|
| Nos. 1 and 2 | 16·8 | per cent. |
| 3 and 4 | 15·1 | „ |
| 5 and 6 | 19·1 | „ |
| 9 and 10 | 25·2 | „ |
| 11 and 12 | 35·9 | „ |
| 13 and 14 | 41·5 | „ |

Showing that the undecomposed excrementitious matter from the horse, the cow, and man, is not so powerful a promoter of the growth of the seedling wheat plant as that of the sheep, the pig, and poultry, and that the two latter are decidedly the most effective of the six.

| | | |
|---|---|---|
| Nos. 15 and 16 | 46·3 | per cent. |
| 17 and 18 | 35·2 | „ |
| 19 and 20 | 32·2 | „ |
| 21 and 22 | ·6 | „ |

The most powerful promoter in the whole being the decomposed stable manure. The two other decomposed organic bodies being also highly effective in favouring the making of carbon by the wheat plant.

These dispose me to infer that there is a considerable difference in the effect produced upon the early growth of the wheat plant by the different kinds of undecomposed excrementitious manures; and that vegetable matter, in a state of decomposition, is more powerful in its immediate effect, than other matter, which has not undergone decomposition; and that this increased effect is greatly produced by miasm, a product of the putrefaction of the different bodies.

In support of these conclusions, may be added the following experiments, which were made with the same kind and quantity of wheat seeds, and another kind of clay and sand, neither of which were previously burned nor acted upon by any acid. The organic matter was supplied to each experiment, in the manner already described, and they were also similarly conducted with respect to water, situation in which they stood, &c.

| No. | | | Weight of dry plants cut close to the earth. |
|---|---|---|---|
| No. 1, | 2·5 grs. | of soluble horse excrement, | 35·4 grs. |
| 2, | 2·5 | do. cow | 38·3 „ |
| 3, | 2·5 | do. sheep | 53·8 „ |
| 4, | 2·5 | do. pigs | 55·4 „ |
| 5, | 2·5 | do. matter from a dung bed | 56·7 „ |
| 6, | 2·5 | do. decayed sea-weed | 61·6 „ |
| 7, | 2·5 | do. do. turnip leaves | 62·4 „ |
| 8, | 2·5 | do. do. young grass | 59·8 „ |
| 9, | 5· | do. horse excrement | 44·2 „ |
| 10, | 5· | do. cow do. | 39·7 „ |
| 11, | to which nothing was added | | 33·6 „ |

From these results, connected with those of other experiments detailed under this head, and especially with those recapitulated in page 159, we are led to conclude that miasm is a powerful agent in stimulating plants in performing their vegetative functions, and that by its influence plants may be made to increase their proportion of carbon to a very considerable extent.*

## THE QUANTITY OF CARBON MADE BY PLANTS IS INFLUENCED BY SALINE AND EARTHY BODIES.

By the judicious application of saline and earthy bodies to land, its power in producing plants is increased. Vegetable physiologists are divided in opinion as to the way in which these bodies act in fertilizing the soil. In this place we shall confine ourselves to the description of experiments, the results of which appear to favour the conclusion, that earthy and saline bodies, when mixed with earth, stimulate plants in making carbon.

---

* My recent experiments upon Guano favour these conclusions. This body, which during its decomposition gives off very little carbonic acid, keeps the atmosphere highly impregnated with miasm.

The first set of experiments were made in the month of May, in common flower-pots, with 50 grains of the red wheat planted in 3,000 grains of equal parts by weight of clay and sand, which had been acted upon by dilute sulphuric acid, repeatedly washed, and afterwards burned.

To No. 1 was added 5 grs. of dry carbonate of soda.
2 „ 5 „ „ potass.
3 „ 5 „ nitrate of potassa.
4 „ 5 „ caustic lime.
5 and 6 water only.

The soluble salts were dissolved in the distilled water, with which the earth was at first moistened; the lime was spread on the bed where the seeds lay about half an inch from the surface.

The flower-pots were placed on saucers, and Nos. 1 to 5 were kept covered with glass shades, external atmospheric communication being cut off by water. No. 6 was exposed to the surrounding air. The seeds all germinated at the same time. The plants in those experiments which contained the soda and the lime appeared the healthiest, and the darkest in colour. When they had stood where the sun shone about half the day for thirty days, the leaves of the plants in those experiments to which nothing but water was added, began to fade. The plants in all the experiments were at this time cut down, and dried. After ten days very little progress in growth was made by any of the fresh shoots. They were again cut down, dried, and mixed, with the former cuttings. The roots and husks were separated from the earth when dry. The different parts of each experiment were analysed, and on comparing the carbon in the proceeds with that in the seeds planted, the results were—

CARBON PER CENT.

| | Independent of that in the Carbonic Acid. | With that in the Carbonic Acid. |
|---|---|---|
| No. 1. | 6·8 increase | 44·6 increase. |
| 2. | 2·0 „ | 32·8 „ |
| 3. | 4·0 „ | 40·0 „ |
| 4. | 10·6 „ | 28·5 „ |
| 5. | 1·2 decrease | 24·2 „ |
| 6. | 0·8 „ | |

By calculating for the carbon in the plants only, we have the carbon increased by the influence of

| | |
|---|---|
| Carbonate of soda | 8·0 per cent. |
| „ potassa | 3·2 „ |
| Nitrate of potassa | 5·2 „ |
| Caustic lime | 11·8 „ |

These saline and earthy bodies, appear to exert a more powerful influence upon the same kind of plants growing in earth free from carbon, but which had not been either burned or acted upon by acids, as appears from the following experiments. They were made with the same materials as those mentioned in page 161, and were conducted in the same manner, except that they were supplied during the whole period with rain, instead of distilled water.

To No. 1 was added 3 grs. of lime.
2 „ 3 „ dry nitrate of soda.
3 „ 3 „ „ carbonate of soda.
4 „ 3 „ „ „ of potassa
5 „ 3 „ „ sulphate of lime.

No 5, like Nos. 16 and 18 of the 20 experiments already referred to, were occasionally kept for four days successively under a glass shade, and the quantity of carbonic acid given off during this period determined.

These experiments all retained their healthy appearance much longer than those to which organic matter was added.

The different experiments, on being prepared and examined, gave for—

| | Grains. | Carbon. | Total Carbon. |
|---|---|---|---|
| No. 1. | | | |
| Leaves and stems.......... | 43·5 | 25·8 | 28·8 |
| Roots and husks .......... | 30·2 | | |
| Earth.................... | .. | 3·0 | |
| No. 2. | | | |
| Leaves and stems.......... | 59·8 | 34·0 | 37·7 |
| Roots and husks .......... | 34·7 | | |
| Earth .................... | .. | 3·7 | |
| No. 3. | | | |
| Leaves and stems.......... | 63·4 | 36·3 | 40·2 |
| Roots and husks .......... | 36·4 | | |
| Earth .................... | .. | 3·9 | |
| No. 4. | | | |
| Leaves and stems.......... | 47·2 | 28·8 | 32·2 |
| Roots and husks .......... | 30·6 | | |
| Earth .................... | .. | 3·4 | |
| No. 5. | | | |
| Leaves and stems.......... | 55·5 | 32·4 | 35·9 |
| Roots and husks .......... | 34·4 | | |
| Earth .................... | .. | 3·5 | |

These gave, for the increase of carbon upon that contained in the seeds planted—

| | | |
|---|---|---|
| By the addition of lime ............ | 43·1 | per cent. |
| nitrate of soda.... | 86·8 | „ |
| carbonate of soda | 100·0 | „ |
| carbonate of potassa | 60·1 | „ |
| sulphate of lime.. | 73·4 | „ |

On comparing the results of these two sets of experiments, we have the increase in the weight of carbon comprised in the leaves, stems, roots, husks, and the earth, when

| | Unburned earth. | Burned earth. |
|---|---|---|
| Carbonate of soda was employed | 100 | 6·8 per ct. |
| „ potassa | 60·1 | 2·0 „ |
| Caustic lime | 43·1 | 10·6 „ |

This difference shows that saline and earthy bodies, as fertilizers of land, act unequally upon different kinds of land.

### THE QUANTITY OF CARBON MADE BY PLANTS IS INFLUENCED BY CARBONACEOUS MATTER LEFT IN THE EARTH BY OTHER PLANTS.

When seeds are planted in earth, containing small portions of organic matter, left after carefully removing the roots, and husks, of preceding plants, the young plants which spring up from these seeds yield carbon, exceeding in weight that originally contained in the seeds, and the earth; and this increase in the weight of carbon, found in the plants thus produced, bears a higher proportion when compared with that comprised in the seeds and the earth, than when they grew in similar earth, wholly free from organic matter.

The experiments which establish this fact were made with 50 grains each, of the red wheat, planted in mixtures of clay and sand in which seedling plants had previously grown; these seedling plants, together with their roots, had been carefully removed, the earths dried, portions of them analysed, by which process the proportionate quantity of carbon they contained was determined. The wheat seeds were then planted in flower-pots containing such a weight of these earths, as comprised three grains of carbon, and supplied during their germination and growth with rain water.

| Nos. | | | | | |
|---|---|---|---|---|---|
| 1. | 3100 | grs. of earth | in which | early pease | had grown |
| 2. | 3250 | ,, | ,, | early turnip | ,, |
| 3. | 3020 | ,, | ,, | rape | ,, |
| 4. | 3360 | ,, | ,, | mustard | ,, |
| 5. | 3410 | ,, | ,, | cress | ,, |
| 6&7. | 3410 | ,, | containing no organic matter. | | |

During the first four weeks, the plants in Nos. 6 and 7 were as strong and as healthy as any of the others; after this period, their stems were more slender, and in five weeks the ends of many of their leaves changed from dark green to brown. They were then cut, for the first time. The fresh shoots made little progress after ten days, and on the fiftieth day of the experiments they were again cut, dried, and mixed with the former. The earths were dried, and the roots and husks carefully removed.

The plants in Nos. 1 to 5 were cut for the first time on the thirty-eighth day, and for the second on the seventieth day of the experiments; when some of them appeared then to be making progress in growth. The roots, and husks, were carefully separated from the earths when dry, the several parts of each experiment, were weighed and analyzed, and gave for—

| | Grains. | Grs. of Carb. | Total Carbon. |
|---|---|---|---|
| No. 1. | | | |
| Leaves and stems | 48·2 | 27·1 | 33·3 |
| Roots and husks | 28·6 | 6·2 | |
| Earth | .. | | |
| No. 2. | | | |
| Leaves and stems | 47·5 | 28·3 | 34·8 |
| Roots and husks | 28·8 | 6·5 | |
| Earth | .. | | |
| No. 3. | | | |
| Leaves and stems | 44·1 | 25·4 | 31·2 |
| Roots and husks | 26·5 | 5·8 | |
| Earth | .. | | |
| No. 4. | | | |
| Leaves and stems | 38·6 | 22·9 | 28·4 |
| Roots and husks | 22·3 | 5·5 | |
| Earth | .. | | |
| No. 5. | | | |
| Leaves and stems | 40·4 | 24·5 | 30·5 |
| Roots and husks | 26·3 | 6·0 | |
| Earth | .. | | |
| No. 6. | | | |
| Leaves and stems | 30·6 | 18·1 | 21·2 |
| Roots and husks | 20·5 | 3·1 | |
| Earth | .. | | |
| No. 7. | | | |
| Leaves and stems | 28·8 | 17 5 | 20·4 |
| Roots and husks | 20·0 | 2·9 | |
| Earth | .. | | |

On comparing the weight of carbon, resulting from the first five of these experiments, in earth which comprised organic matter left by other plants; with that resulting from No. 6, which earth was free from carbon; we have carbon made by the influence of the organic matter left by—

grs. per cent.
Pease... .33·3 —21·2 —3 = 9·1..equal to 42.9
Turnip ....34·8 „ =10 6 „ 50·0
Rape ....31·2 „ = 7·0 „ 33·0
Mustard ..28·4 „ = 4·2 „ 19·8
Cress ....30·5 „ = 6·3 „ 29·7

In the experiments before us we have organic matter containing three grains of carbon left by

| | | | | |
|---|---|---|---|---|
| Pease, | favouring | the making of | 9.1 | grains of carbon. |
| Turnip | „ | „ | 10·6 | „ |
| Rape | „ | „ | 7·0 | „ |
| Mustard | „ | „ | 4·2 | „ |
| Cress | „ | „ | 6·3 | „ |
| Nos. 6 and 7, earth and water only | | | 1·1<br>0·3 | „<br>„ |

Shewing that the increase by the influence of water only, was small when compared with that proceeding from the influence of the organic matter left in the earth by preceding plants.

## THE QUANTITY OF CARBON MADE BY PLANTS IS INFLUENCED BY THE WATER SUPPLIED TO THEM.

The quantity of carbon made by plants is influenced both by the kind, and the quantity of water with which they are supplied. Seedling plants growing in barren earth, moistened with distilled water, do not yield so much carbon as they do if supplied with rain water, equally free from carbonaceous matter. When seedling plants are supplied with water, holding in solution some of the metallic oxides; the weight of carbon they yield is less, than when water is used which holds in solution earthy and organic salts. Again, when seedling plants are supplied with various proportions of the same kind of water; the weight of carbon resulting from each experiment, to a certain extent, bears a direct proportion to the quantity of water supplied to each. It is this feature which more especially claims our attention in this place: for it would seem from some of the experiments, upon the making of carbon by plants, already described; that the most barren land might, in a few years, be converted to fruitful fields; a circumstance at variance with practical experience.

The following experiments are intended to prove that the difference between this experimental evidence and practical results is due to the quantity of water retained by the earth in which the plants grow; and that though it is easy within the limits of an experiment to change the relative character of the earth, yet, to effect such a change by the same means in a tract of barren land is impracticable.

Five experiments were prepared, similar in every respect to Nos. 21 and 22, page 164, with these exceptions:—Flower-pots were taken whose apertures at the bottom increased in size with their number: the aperture of No. 3, was three, and that of No. 5, was six times the size of that of No. 1. This increase in the size of the apertures favoured the draining of the water so much; that whereas the plants in No. 1 might be considered as growing in very moist earth, those in No. 4 were in very dry, and those in No. 5, in earth which scarcely retained sufficient water to favour the vegetation of the plants. The earths which constituted the different experiments were kept in an equally moist state, until the seeds in each had germinated. The water supplied to each varied in an inverse ratio to the size of the aperture of the several pots.

| | Grains. | Grs. of Carb. | Total Carb. |
|---|---|---|---|
| No. 1. | | | |
| Leaves and stems .......... | 37·2 | 18·8 | 22·6 |
| Roots and husks .......... | 17·0 | | |
| Earth .................... | .. | 3·8 | |
| No. 2. | | | |
| Leaves and stems .......... | 33·8 | 17·5 | 21·1 |
| Roots and husks .......... | 16·0 | | |
| Earth .................... | .. | 3·6 | |
| No. 3. | | | |
| Leaves and stems .......... | 26·4 | 13·8 | 16·2 |
| Roots and husks .......... | 14·6 | | |
| Earth .................... | .. | 2·4 | |
| No. 4. | | | |
| Leaves and stems .......... | 12·2 | 8·9 | 10·3 |
| Roots and husks .......... | 12·6 | | |
| Earth .................... | .. | 1·4 | |
| No. 5. | | | |
| Leaves and stems .......... | 7·3 | 5·4 | 6·2 |
| Roots and husks .......... | 10·8 | | |
| Earth .................... | .. | 0·8 | |

On comparing the weight of carbon obtained from these experiments with that in the seeds planted, we have, when the plants were—

| | Increase per cent. | Decrease per cent. |
|---|---|---|
| Very plentifully supplied with water | 11·6 | |
| Plentifully „ „ | 4·8 | |
| Sparingly „ „ | | 19·5 |
| Very sparingly „ „ | | 49·9 |
| In nearly a constant draught | | 69·2 |

These results, shew how much plants are indebted to a plentiful supply of water for their luxuriant growth; and how much their vegetative functions are under the influence of moisture. They also show that barren earth, in which seeds are planted, when plentifully supplied with water, will yield twice the weight of dry plants, and retain twice as much organic matter serviceable for future plants; as when the earth is sparingly supplied with water.

Had other seeds been planted in these several earths, the organic matter left in the soil by the seedling plants would have been greater than before; and thus we see that however barren any earth may be to begin with, the repeated growth of plants kept plentifully supplied with water, will, in a few years, enrich it with organic matter, and render it comparatively fruitful; a state of things, the proof of which lies within the limits of an experiment; but a practical exemplification on the barren rock, or sandy desert, lies far beyond our reach.

I trust sufficient evidence has been advanced to establish the principle, that carbon is a vegetable product made by plants, and that the quantity so made, varies with particular incidents belonging to the air, the earth, and the water, in which they grow.

It only remains to enquire, whether this experimental evidence is confirmed by practical results, and borne out by common experience.

In the course of the preceding chapters I have often had occasion to remark, that the results obtained from my experiments, were in perfect agreement with practical experience. — I subjoin the following statement of circumstances, which came under my own observation, and which appear to furnish a practical illustration of the principle above contended for—that plants make carbon.

When on a visit to Cumberland, in 1840, I was informed, that previously to the last six years, a tract of marsh land, between Skinburness and Brownrig, in that county, of about three miles in length, by the side of the river Waver, had, by the joint agency of the river and the tide waters, been gradually washed away.

During the last six years, under the direction of the Marsh committee,* so much as 275 acres of this land have been reclaimed at an expense of £41. 18s., with a prospect (at little, if any additional expense) of a further annual saving for several years to come.

The committee, acting under the impression that the wasting of this marsh land, was principally owing to the great number of small water-courses which intersected the marsh, and ran into the river; caused open drains to be cut on the high marsh, so as to convey all the fresh water, by two large drains, into the river.

On viewing this land, I observed that the part first reclaimed, was covered with turf, and regularly pastured. The next reclaimed was fast covering with grass. On some of that more recently thrown up were small plots of grass. On other portions there were several sprigs of samphire growing; and on many parts of the last reclaimed, there were beds of marine *conferva.*

---

* Messrs. Peat, Bigg, Glaister, and Fairlim.

It occurred to me, that a careful analysis of these soils, might shew that this newly reclaimed marsh land had increased in vegetable matter, to a greater amount than possibly could be derived from the atmosphere and the salt water; a fact, which, if established, would furnish the strongest practical evidence in favor of the above principle, especially as the land was supplied with no manure, but what was furnished by the cattle pasturing on the marsh, for six months in the year. This idea was strengthened, by knowing that the chemical constitution of those plants which grew under such circumstances, is such, that they appear to have the power, during their growth, of making carbon to a great extent.

On the 17th of July, 1840, samples of the marsh grass, conferva, and six specimens of the sandy soil, were collected and dried at a temperature not exceeding 130°, Fahrenheit. They were afterwards folded in paper, where they acquired the hygroscopic state of the atmosphere, until they were experimented upon; when the following results were obtained.* The earthy constituents of these soils, not forming so much the object of my research as the vegetable, my attention in the analysis was more particularly confined to discover the quantity of organic matter.

---

* The quantity of each sample of soil procured, was insufficient for purposes beyond such analysis of the earthy ingredients as are here given.

The subject of the first analytical experiment was the conferva gathered from the recently formed sandy soil, of sample No. 3. As the sand which adhered to it was not washed off, the ashes in the analysis shew a portion of earthy matter which did not form a part of the plant. It was constituted of—

| | |
|---|---|
| Carbon | 28·5 |
| Hydrogen | 4·0 |
| Oxygen | 33·2 |
| Nitrogen | 2·2 |
| Ashes | 32·1 |
| | 100 |

In my former investigations into the apparent influence of nitrogen on the growth of plants,* and in my more recent researches on the decomposition of vegetable matter; and on the compound nature of carbon; my attention had been particularly called to the apparent activity of nitrogen, in bringing about spontaneous chemical action.

The conferva, containing 7·7 per cent. by weight of nitrogen, for every 100 of carbon, may be considered as favourably constituted for quick growth, for making carbon, during the regular and healthy performance of its functions, and also as susceptible of rapid decay, when placed in favourable circumstances.

The marsh-grass plant, No. 2, the roots of which rather resemble those of couch-grass, spreads over the ground rapidly. The proportion of nitrogen it contains, is also great when compared with the carbon. The sample gathered and dried, in the manner already mentioned, was found upon analysis, to be composed of—

---

* Philosophical Transactions, for 1839.

| | |
|---|---|
| Carbon | 37·13 |
| Hydrogen | 6·30 |
| Oxygen | 44·59 |
| Nitrogen | 2·48 |
| Ashes | 9·50 |
| | 100· |

No. 3.—The constitution of the soil from whence the conferva was taken, after being freed from every fibre of the plant, was—

| | |
|---|---|
| Carbon | ·55 |
| Nitrogen | ·04 |
| Water, about | 3·82 |
| Vegetable matter and water | 4·41 |
| Soluble salts, principally common salt | 1·07 |
| Earthy carbonates | 1·82 |
| Principally silicious sand, with about six per cent. of aluminous earth | 92·7 |
| | 100· |

No. 4.—This sample was taken from the same bed of reclaimed soil which had been deposited by the sea-water, with the last-mentioned experiment. It was taken at a distance of about two feet, in a direct line from whence the former was dug.

These two samples of earth were apparently alike in every respect, with this exception:—the former was covered with the marine conferva; the latter was entirely free from every vestige of plant. No. 4 was composed of—

| | |
|---|---|
| Carbon | ·46 |
| Nitrogen | ·03 |
| Water, about | 3·61 |
| Vegetable matter and water | 4·10 |
| Soluble salts—principally common salt | 1·02 |
| Earthy carbonates | 1·83 |
| Sand, with about six per cent. of clay | 93·05 |
| | 100· |

No. 5.—Soil from underneath the first perfect formation of grass. The portion subjected to analysis in this, and the two following experiments, was taken from two to three inches from the surface, and contained several grass roots. It was composed of—

| | |
|---|---|
| Carbon | ·962 |
| Nitrogen | ·102 |
| Water, about | 4·446 |
| Vegetable matter and water | 5.51 |
| Common salt | ·60 |
| Carbonate of soda and potassa | ·21 |
| Carbonate of lime | 1·40 |
| Silicious sand, with about 7 per cent. of clay | 92·28 |
| | 100· |

No. 6.—Soil taken about two inches from underneath the surface of that reclaimed marsh, which

had been covered with grass, for two years, was composed of—

| | |
|---|---|
| Carbon | 1·22 |
| Nitrogen | ·12 |
| Water, about | 4·86 |
| Organic matter and water | 6·20 |
| Soluble salts | ·71 |
| Earthy carbonates | 1·10 |
| Chiefly silicious sand and aluminous earth | 91·99 |
| | 100 |

No. 7.—A fertile part of the old-marsh soil. The portion analysed, was taken from two to three inches beneath the surface, and was constituted of—

| | |
|---|---|
| Carbon | 1·83 |
| Nitrogen | ·13 |
| Oxygen and hydrogen, say | 2·74 |
| Dry organic matter | 4·70 |
| ·35 of which was soluble in hot water, making the soil constituted of dry insoluble organic matter | 4·35 |
| Soluble ditto ditto | ·35 |
| Water, about | 3·00 |
| Soluble salts | ·12 |
| Earthy carbonates | ·80 |
| Silicious sand | 82·88 |
| Clay | 8·50 |
| | 100 |

No. 8.—A sample of the old marsh land, taken from a depth of eighteen inches. It contained several roots of the marsh grass, which would con-

tribute to the quantity of organic matter obtained by analysis. It was composed of—

| | |
|---|---|
| Carbon | ·646 |
| Nitrogen | ·042 |
| Water, about | 3·962 |
| Organic matter and water | 4·65 |
| Soluble salts | ·56 |
| Earthy carbonates | 1·70 |
| Sand and clay, the latter being about 6 per cent. | 93·09 |
| | 100· |

The soils of which these experiments were made, being perfectly free from the plants which covered them, the results obtained by analysis, may be regarded as fair representations of the constitution of each soil, irrespective of the vegetables which grew upon them.

If we regard the constitution of No. 4, in which no plants had made their appearance, as containing the proportion of organic matter, originally in each soil; and if we make our calculation for the weight of the carbon in the vegetable matter carried off from each part by the pasturage of cattle, as equivalent to the amount of the carbon contributed to the same, we may presume that the excess of carbon is produced by plants.

Taking these as the bases of our calculation, we have the quantity of carbon made by the plants in the respective soils as under, viz. :—

| | | | | | | |
|---|---|---|---|---|---|---|
| In No. 3 | ·55 | −·46 = | ·09 | equivalent to | 19·8 | per cent. |
| 5 | ·962 | −·46 = | ·502 | do. | 113·6 | „ |
| 6 | 1·22 | −·46 = | ·76 | do. | 165·6 | „ |
| 7 | 1·83 | −·46 = | 1·37 | do. | 300· | „ |

Thus the conferva which had grown upon No. 3

shows by this mode of research, that the land on which it grew was enriched in organic matter near 20 per cent. The plants which had grown upon No. 5 had enriched their soil 113 per cent.; those upon No. 6, 165 per cent., and those upon the old marsh land 300 per cent.

If plants have the power of making vegetable matter, and if the increase in the above calculations be due to this source principally, we are in a situation to account for the increased fertility of some lands which have year after year produced plants, no part of which has been removed. And we also see why some good land is not impoverished by carrying off its produce in consecutive years. The marsh land, the subject of these experiments, may be considered as an instance of this, to a certain extent. The cattle which pastured upon this marsh during six months in the year increased in size, and fattened upon the produce of this soil; and thus carried off a certain quantity of vegetable matter which had undergone animal assimilation, an equivalent to which they did not return.

In whatever manner then we conduct our investigations, whether experimentally or practically, on examining all the phenomena which accompany both the one and the other, the results lead to the same conclusion,—all tending to prove that carbon is made by plants in quantities varying with the circumstances under which they are placed.

# PART II.

## DECOMPOSITION OF CARBON DURING THE PUTREFACTIVE FERMENTATION.

### PUTREFACTIVE FERMENTATION.

WHEN animal or vegetable matter, as elaborated by the animal or plant, but in which the principle of life has been destroyed, is kept in a state of moisture, and exposed to the air at a temperature varying from 45° to 100°, it undergoes a process by which the character of its organization is changed, and a new organization is produced. When this change is accompanied by a noxious effluvia, the process is called putrefactive fermentation.

### SIGNS OF THE DECOMPOSITION OF CARBON DURING THE PUTREFACTIVE FERMENTATION.

It occurred to me many years ago, on examining certain experiments, that vegetable matter, during the process of putrefactive fermentation, sustained a loss of carbon which could not be accounted for upon any known principle. I observed also, that together with this loss of carbon there was a quantity of water produced which was equally unaccountable; and these circumstances led me to suspect that carbon itself underwent decomposition.

At a later period, a long course of experimental investigation furnished me with indirect, but striking evidence, that carbon was a compound body, and that water, or its elements oxygen and hydrogen, were largely included in its composition. But the many unsuccessful attempts to decompose this supposed element, by means of the most powerful agents, employed by the ablest chemists both in this and in other countries; made me hesitate in yielding my assent to any indirect evidence in support of such a proposition.

In order to obtain a conclusive test, whether carbon was an ultimate element or a compound body, and whether by any process of nature that decomposition was effected, which skill had failed to accomplish, I commenced a series of experiments with this one object in view.

In making experiments upon natural processes, there is a difficulty which the greatest care can hardly overcome, for nature is so exceedingly nice in her operations, that the slightest change in exposure, position, or temperature, will produce a change in the results. Accordingly, of the great number of experiments I at first made, some underwent one change, and some another; so that out of five and six experiments made upon the same mixtures, I am not aware that any two were similar in all their results; yet the loss of carbon was an invariable result in them all.

If vegetable matter be thrown into a heap, the surface which is exposed to the air undergoes a chemical change, which may be illustrated by regarding 16 parts by wt. of atmospheric oxygen combining with 6 do. of carbon in the organic matter, and constituting 22 do. of carbonic acid gas.

A variety of other new products, many of which are soluble in cold water, appear to be formed. These new products, when kept under these circumstances, appear to be susceptible of chemical changes, the nature of which have not been sufficiently inquired into, to enable us to speak upon them with any degree of certainty. Drawing our inferences from the results of our best experiments, it is probable that the chemical changes effected upon these new products, are more independent of the oxygen of the atmosphere than those which occur during the early part of the putrefactive process. We have the practical evidence showing us, that this decomposing heap, if allowed to remain for two or three years, during which it emits a noxious effluvia, becomes a black compact substance like peat, consisting of hydrogen, oxygen, and nitrogen, in combination with various alkaline and earthy bodies, and a little carbon; but the principal part of the carbon has disappeared.

The gaseous products of the putrefaction of organic matter; are, first carbonic acid gas, consisting of carbon and oxygen in the proportions above-mentioned. This gas forms from 95 to 99 per cent. of the entire volume of the gaseous products. Secondly, carburetted hydrogen, consisting of carbon and hydrogen in the proportions by weight of 6 of carbon to 1 hydrogen, or of some multiples of these weights. The volume of this gas is generally so small, that it is only appreciable by very delicate modes of experimenting, and rarely, if ever, amounts to $\frac{1}{200}$ part of the gaseous products. Thirdly, ammonia, consisting of—

| | | |
|---|---|---|
| Hydrogen ........ | 3 | parts by weight. |
| Nitrogen.......... | 14 | do. |
| Ammonia...... | 17 | |

To these must be added miasm, which can be better appreciated by the senses, than its constitution determined by any chemical means.

There is a great difference in the degrees of rapidity with which different sorts of vegetable matter pass into decay. This tendency to rapid decay, will generally be found to vary in an inverse ratio to the quantity of carbon contained in the plant, or its different parts. For example, the *heartwood* of the oak, which comprises when felled about 43 per cent. of its weight of carbon, may be kept for many years, under circumstances favourable for putrefactive fermentation, without undergoing any perceptible chemical change; but the leaves of the same tree, which contain about 9 per cent. of carbon under similar circumstances, will putrefy in a few days. The tender herb, which contains about 4 per cent. of its weight of carbon, begins to decay in a few hours after it is cut; but the full grown plant, containing from 20 to 30 per cent. of the same body, will remain unchanged for many days.

### THE VOLUME OF CARBONIC ACID.

The volume of carbonic acid resulting from the putrefaction of vegetable matter, cannot at all times be measured by that of the oxygen which has disappeared from the atmosphere. It varies, both with the material which is undergoing the chemical change, and with the stage of the process. Thus, for example, if we make an experiment with *heart-wood* in powder, either in its fresh state or in a partially decayed condition, the volume of carbonic acid which results from the chemical action, in many instances, so closely approximates to that of the oxygen which has been removed from the atmosphere, that we may regard the one as having been formed at the expense of the other. But this is by no means universally the case, for it not unfrequently happens, that the volume of carbonic acid is less than that of the oxygen which has disappeared from the surrounding air. When the experiment has been tried upon cabbages, or other succulent plants, I have met with no instance in which the volume of the carbonic acid removed from the subject of experiment, was equal to that of the oxygen which had disappeared from the atmosphere. When fruit or tender herbs are made the subject of experiment, there is nothing more uncertain than the volume of carbonic acid, when compared with that of the oxygen removed from the surrounding air. This might in part be accounted for, upon the supposition that some of the juices pass first into the vinous, and afterwards into the *acetous* fermentation. But making the most liberal allowance for this supposition, we still find, on continuing these experiments, the greatest departure from the rule,—that the volume of carbonic acid which is given off is exactly equal to that of the oxygen removed from the atmosphere.

In the decomposition of all kinds of vegetable matter, I have found that as soon as the putrefying mass appears to be under a uniform process, producing blue, green, yellow, or any other kind of mould, the volume of carbonic acid is always less than that of the oxygen which has disappeared from the atmosphere; and this difference between the two volumes, varies with the appearance of the putrid bodies, and especially with the colour of the mould.

### SOLUBLE MATTER FORMED DURING THE PUTREFACTION OF VEGETABLES.

Putrefactive fermentation seems to be a process by which vegetable bodies are rendered more soluble in water. Fresh turnips or cabbages yield to cold water very small quantities of soluble compounds; but when they begin to decay, they yield more and more of these compounds, as the putrefactive fermentation increases.

The weight of this soluble matter, compared with the weight of the plant from which it is formed, varies with the kind of plant and its degree of maturity. Young and tender plants yield much more than those which have attained maturity.

By allowing plants to pass into decay, those earthy and alkaline bodies which formed their skeleton, and which were in the fresh plant to a great extent insoluble, became soluble in cold water. The solubility of the bodies thus formed also varies with the kind and maturity of the plants which have undergone putrefaction. Cold water will hold in solution

| By weight. | Of that by the putrefaction of |
|---|---|
| 7 per cent. | Sea weed |
| From 5 to 6 ditto | Succulent plants |
| „ 3 to 4 ditto | Stable manure |
| About 3 ditto | Straw |
| „ 1 ditto | Wood |

We experience considerable difficulty in accurately determining the weight of the soluble bodies formed during the putrefactive fermentation. If we attempt to determine this quality by evaporating the water of solution, a loss of the dissolved body is sustained; and this loss appears to bear a direct proportion to the temperature at which the solutions are dried, and the miasm given off during the process. The following experiments furnish us with an instance of this:—

Two portions of fluid (each weighing 1,000 grains), specific gravity 1013, obtained from stable manure, which had been under putrefaction for nine months, were dried; No. 1 at a temperature not exceeding 110°; 860 grains of No. 2, were evaporated at a boiling temperature, and the rest at and under 110°.

| | | | | | |
|---|---|---|---|---|---|
| The dry matter from | | | No. 1 weighed | 30·8 | grains. |
| „ | „ | „ | No. 2 „ | 29·6 | „ |

On redissolving them in water, and making the weight of the solution 1,000 grains, the specific gravity was—

| | |
|---|---|
| No. 1 | 1012·4 |
| No. 2 | 1011·8 |

On again evaporating the two to dryness at 110°, their weight of dry matter was from—

| | |
|---|---|
| No. 1 | 29·5 |
| No. 2 | 28·6 |

And on again dissolving them, their specific gravity was—

| | |
|---|---|
| No. 1 | 1011·7 |
| No. 2 | 1011·2 |

By the first process of desiccation, it appears that the loss sustained by drying at and under 110°, was equal to 5 per cent.; and that, by first evaporating a part of the water at the boiling temperature, and the rest at 110°, 9·2 per cent.

Of the chemical constitution of the mere volatile matter which passes off along with the water, during the process of desiccation, we are entirely ignorant. Our knowledge of the influence of miasm upon the growth of plants, would lead us to infer, that by drying the putrified matter, even at a low temperature, a loss of its stimulating or nutritive properties is sustained; which loss bears a direct proportion to the height of the temperature at which they are dried.

I have occasionally kept solutions of this kind under experiment, confined within glass shades. All that I have been able to make out is, that the carbon in the volume of carbonic acid given off, forms but a small portion of that which disappears from the liquid; and that the atmosphere is always highly charged with miasm.

We have no mode of experimenting by which we can determine what proportion of the soluble *organic* putrid *matter* enters directly into the roots of plants; and what proportion undergoes a further decomposition, which has for one of its products carbonic acid. All that we can find out by experiment is, that it favours the growth of plants much more than insoluble and undecomposed organic matter: that some kinds of soluble organic putrid matter promote the growth of plants more than others; and that kind, most, which gives off the greatest quantity of miasm.

If solution by water, of decayed organic matter in soils, were a necessary condition to its being serviceable for the growth of plants; the quantity of rain which falls upon the earth annually, is sufficient to dissolve several times the quantity of organic matter found in the constitution of plants. By considering the solubility of the decayed matter in soils, at one per cent. only; an annual fall of rain, twenty inches deep, would dissolve a quantity, containing as much carbon as is comprised in the produce of eight years.

On testing the solutions, obtained from decayed vegetable matter, to ascertain the presence of uncombined alkalies or acids, we more generally find the former; but it not unfrequently happens that a free acid is present. This is very generally the case, during the early decomposition of the leaves of trees.

Though some of the soluble bodies, formed during the putrefaction of different vegetable substances, agree in many of their chemical properties; on separating them, by proximate analysis, or subjecting the entire mass to ultimate analysis, they are found to vary in chemical constitution, in almost every kind of plant from which they are formed. This will appear from the following analyses. To prevent as much as possible the loss of organic matter, by evaporating the water of solution in the preparation of the different substances, they were never exposed to a temperature exceeding 110°. Nos. 1, 2, 3, and 4, when subjected to ultimate analysis, were in a state of powder; Nos. 5, 6, and 7, in a state of semi-fluid; and Nos. 8 and 9, were in a condition resembling paste.

No. 1.—Dark brown powder, obtained from the soluble part of stable manure, which had been under decomposition, in the dunghill, for seven months.

| | |
|---|---|
| Carbon | 20·13 |
| Hydrogen | 4·71 |
| Oxygen | 34·08 |
| Nitrogen | 1·98 |
| Ashes | 39·10 |
| | 100· |

No. 2.—Brown powder, obtained from the soluble portion of putrid cinquefoil, which had been in a bottle without a cork, for more than six months, was constituted of—

| | |
|---|---|
| Carbon | 22·6 |
| Hydrogen | 6·3 |
| Oxygen | 40·4 |
| Nitrogen | 3·2 |
| Ashes | 27·5 |
| | 100· |

The cinquefoil, previously to its being put into the bottle, and dried at 110, was constituted of—

| | |
|---|---|
| Carbon | 35·40 |
| Hydrogen | 6·44 |
| Oxygen | 43·75 |
| Nitrogen | 4·01 |
| Ashes | 10·40 |
| | 100· |

No. 3.—Powder from the soluble part of putrid sunflower leaves, which had been in a bottle without a cork for seven months, during which a small

portion of rain water was added to the putrifying mass, was constituted of—

| | |
|---|---|
| Carbon | 22·5 |
| Hydrogen | 6·5 |
| Oxygen | 42·3 |
| Nitrogen | 4·1 |
| Ashes | 24·6 |
| | 100· |

The original constitution of the leaves, dried at 110°, was—

| | |
|---|---|
| Carbon | 33·7 |
| Hydrogen | 5·9 |
| Oxygen | 41·9 |
| Nitrogen | 4·0 |
| Ashes | 14·5 |
| | 100· |

No. 4.—The powder from the putrid hollyhock leaves, which had been similarly treated as those from the sunflower, was constituted of—

| | |
|---|---|
| Carbon | 19·6 |
| Hydrogen | 6·1 |
| Oxygen | 41·0 |
| Nitrogen | 3·8 |
| Ashes | 29·5 |
| | 100· |

Some of the same kind of leaves, dried at 110°, were constituted of—

| | |
|---|---|
| Carbon | 36·7 |
| Hydrogen | 5·8 |
| Oxygen | 42·1 |
| Nitrogen | 3·8 |
| Ashes | 11·6 |
| | 100· |

No. 5.—Putrid semi-fluid, obtained from pease, to which their own weight of water was added and which had undergone putrefaction, for three years, in a bottle rather loosely corked, was constituted of—

| | |
|---|---|
| Carbon | 24·7 |
| Hydrogen | 9·6 |
| Oxygen | 57·7 |
| Nitrogen | 2·6 |
| Ashes | 5·4 |
| | 100· |

The pease in their dry state, were constituted of—

| | |
|---|---|
| Carbon | 40·1 |
| Hydrogen | 5·5 |
| Oxygen | 48·8 |
| Nitrogen | 4·2 |
| Ashes | 1·4 |
| | 100· |

No. 6.—Semi-fluid, obtained from turnip leaves which had become putrid, by being kept, for six months, in a bottle without a cork, was constituted of—

| | |
|---|---|
| Carbon | 26·84 |
| Hydrogen | 7·68 |
| Oxygen | 46·66 |
| Nitrogen | 3·32 |
| Ashes | 15·50 |
| | 100· |

The turnip leaves, previously to their being put into the bottle, after being dried at 110°, were composed of—

| | |
|---|---|
| Carbon | 35·2 |
| Hydrogen | 5·4 |
| Oxygen | 43·3 |
| Nitrogen | 3·6 |
| Ashes | 12·5 |
| | 100· |

No. 7.—The soluble part of putrid cabbage leaves, which had undergone putrefaction in an air-tight vessel, which was only opened twice during the eleven months they were under experiment. The portion subjected to analysis, was prepared from the putrid liquid, by drying, at a low temperature, until it was of the consistency of a thick semi-fluid, when it was constituted of—

| | |
|---|---|
| Carbon | 25·50 |
| Hydrogen | 8·55 |
| Oxygen | 47·82 |
| Nitrogen | 3·92 |
| Ashes | 14·21 |
| | 100· |

The original constitution of the leaves, when dried at 120°, was—

| | |
|---|---|
| Carbon | 35·18 |
| Hydrogen | 6·15 |
| Oxygen | 49·39 |
| Nitrogen | 3·08 |
| Ashes | 6·20 |
| | 100· |

No. 8.—A pasty substance, obtained from the soluble parts of vine leaves, which had become putrid, by remaining in a corked bottle for more than two years, was constituted of—

| | |
|---|---|
| Carbon | 28·11 |
| Hydrogen | 4·86 |
| Oxygen | 22·10 |
| Nitrogen | 6·83 |
| Ashes | 38·10 |
| | 100· |

A sample of the same vine leaves, dried at 110°, immediately after they were gathered, was constituted of—

| | |
|---|---|
| Carbon | 37·7 |
| Hydrogen | 5·3 |
| Oxygen | 42·4 |
| Nitrogen | 5·1 |
| Ashes | 9·5 |
| | 100· |

No. 9.—A pasty substance, from the soluble parts of putrid sea-weed, which had been kept two years in a close vessel, was comprised of—

| | |
|---|---|
| Carbon | 8·7 |
| Hydrogen | 2·8 |
| Oxygen | 39·2 |
| Nitrogen | 1·5 |
| Ashes | 47·8 |
| | 100· |

The sea-weed, dried two days after it was gathered, was constituted of—

| | |
|---|---|
| Carbon | 27·3 |
| Hydrogen | 5·8 |
| Oxygen | 61·3 |
| Nitrogen | 1·4 |
| Ashes | 4·2 |
| | 100· |

I believe that the changes which took place in experiments Nos. 1, 5, 7, 8, and 9, are the same as occur when similar substances are laid up in large heaps, as in a dunghill; and that the changes effected in Nos. 2, 3, 4, and 6, are, in a great measure, similar to those which take place when grass, turnip leaves, wood, and leaves of trees, are allowed to rot on the ground.

If the putrid solutions, above analyzed, had either been dried at a higher temperature, or continued longer exposed to the temperature by which they were brought to the state of powder, semi-fluid, or paste, they would have been deprived of a considerable portion of hydrogen and oxygen, in the proportions in which they form water. These analyses shew a portion of water which does not form a part of the dry, putrid, soluble matter, or fresh plant; and any comparison of these elements in the putrid, and the fresh plant, will be imperfect. But, inasmuch, as in each of these analyses there is a portion of hydrogen or oxygen, more than *that* proportion in which they form water; and as this may be regarded a part of the putrid solution, or the fresh plant, this excess, of either the one or the other, may be safely used in a comparative sense, in any part of our further enquiries.

In order to ascertain the constitution of the soluble matter, obtained from the various putrid solutions as compared with that obtained from the fresh plants, I have set down in the following table the proportions in which this hydrogen or this oxygen exceeds, when compared with 100 parts of carbon, as found by analysis in each substance. In other columns in the same table is shown the proportions of nitrogen and of ashes, when compared with the same weight of carbon.

| | | Carb. | Hydr. | Oxygen | Nitro. | Ashes |
|---|---|---|---|---|---|---|
| | No. 1. | | | | | |
| Stable manure | | 100 | 2·24 | .. | 9·89 | 194·0 |
| | No. 2. | | | | | |
| Cinquefoil | After decomposition | .. | 5·39 | .. | 14·16 | 121·7 |
| | Before do. | .. | 2·74 | .. | 11·33 | 29·4 |
| | No. 3. | | | | | |
| Sunflower leaves | After decomposition | .. | 5·33 | .. | 18·22 | 109·3 |
| | Before do. | .. | 2·06 | .. | 11·89 | 43·0 |
| | No. 4. | | | | | |
| Hollyhock leaves | After decomposition | .. | 5·10 | .. | 19·39 | 150·5 |
| | Before do. | .. | 1·39 | .. | 10·35 | 31·6 |
| | No. 5. | | | | | |
| Peas | After decomposition | .. | 9·89 | .. | 10·53 | 21·9 |
| | Before do. | .. | .. | 10·99 | 10·47 | 3·4 |
| | No. 6. | | | | | |
| Turnip leaves | After decomposition | .. | 6·93 | .. | 12·37 | 57·9 |
| | Before do. | .. | .. | .. | 10·23 | 35·4 |
| | No. 7. | | | | | |
| Cabbage leaves | After decomposition | .. | 12·55 | .. | 15·37 | 55·6 |
| | Before do. | .. | .. | ·55 | 8·75 | 17·6 |
| | No. 8. | | | | | |
| Vine leaves | After decomposition | .. | 7·44 | .. | 24·36 | 135·9 |
| | Before do. | .. | .. | .. | 14·85 | 25·2 |
| | No. 9. | | | | | |
| Sea-weed | After decomposition | .. | .. | 204·59 | 17·24 | 549·4 |
| | Before do. | .. | .. | 54·58 | 5·12 | 15·7 |

We first notice in these analytical results, and the calculations based upon them, that the excess of hydrogen is not very variable, in three out of the four of these different putrid substances. This excess, when compared with 100 parts by weight of carbon in the same body, is, in the experiment with

| | |
|---|---|
| Cinquefoil | 5·39 |
| Sun-flower leaves | 5·33 |
| Hollyhock do. | 5·10 |
| Turnip do. | 6·93 |

We do not find the same regularity in the proportion of nitrogen to carbon in these experiments. The comparative quantity of nitrogen to 100 parts of carbon, in the putrid substances, is—

| | | |
|---|---|---|
| In Cinquefoil | 14·16 | parts by weight. |
| Sunflower leaves | 18·22 | do. |
| Hollyhock do. | 19·39 | do. |
| Turnip do. | 12·37 | do. |

Showing an increase upon that in the fresh plants, in the

| | |
|---|---|
| Cinquefoil | 2·83 |
| Sunflower leaves | 6·33 |
| Hollyhock do. | 9·04 |
| Turnip do. | 2·14 |

This want of uniformity appears greater when we take into account the ashes comprised in the soluble body, and the proportion which they bear to the carbon. These give, for every 100 parts of carbon in the

| | | |
|---|---|---|
| Cinquefoil | 121·7 | parts of ashes. |
| Sunflower leaves | 109·3 | do. |
| Hollyhock do. | 150·5 | do. |
| Turnip do. | 57·9 | do. |

Showing an increase upon those of the fresh plant—

| | | |
|---|---|---|
| Cinquefoil | 92·3 | parts of ashes. |
| Sunflower leaves | 66·3 | do. |
| Hollyhock do. | 118·9 | do. |
| Turnip do. | 27·5 | do. |

In the experiments made with pease, cabbage leaves, and vine leaves, decomposed under close vessels, and which, like the interior of a heap of decomposing vegetables, are only partially exposed to the action of the air; the weight of the hydrogen exceeds that of the oxygen in a degree higher than when the rotting leaves are fully exposed to the atmosphere.

On comparing this excess of hydrogen with 100 parts by weight of carbon, we have in the experiment with

| | |
|---|---|
| Pease | 9·89 |
| Cabbage leaves | 12·55 |
| Vine leaves | 7·47 |

Which, when compared with the proportions in the fresh plants, give for the excess in the

| | |
|---|---|
| Pease | 10·26 |
| Cabbage leaves | 12·62 |
| Vine leaves | 7·47 |

The results of the experiment with sea-weed, to which was added at the commencement a considerable portion of water, are very different. This experiment gives an excess of as much oxygen, as would have required 25·6 parts of hydrogen to convert it into water, and when compared with that of the fresh plant 18·8 parts.

On comparing the quantity of nitrogen in the same experiment, it is less uniform than that of the hydrogen. In the experiment with

| | |
|---|---|
| Pease, its weight is | 10·53 parts. |
| Cabbage leaves | 15·37 „ |
| Vine leaves | 24·36 „ |

Being an increase upon that contained in the fresh plant, in the

| | |
|---|---|
| Pease | ·06 |
| Cabbage leaves | 6·60 |
| Vine leaves | 9·51 |

The proportion of ashes in this experiment is also very different. Their weight is, in the experiment upon the

| | |
|---|---|
| Pease | 21·9 |
| Cabbage leaves | 55·6 |
| Vine leaves | 135·9 |

Being an increase upon that in the fresh plants in the

| | |
|---|---|
| Pease | 18·5 |
| Cabbage leaves | 38·0 |
| Vine leaves | 110·7 |

Similar conclusions to those above-mentioned, may be deduced from the results of experiments, made with a view to discover those chemical changes which take place in the soil; when plants are buried in the earth by the plough.

Into a mixture, composed of one-third silicious sand and two-thirds clay, free from organic matter, was put so much of the following vegetable substances, as in a dry state would be equal to 5 per cent. of the weight of the entire mixture, being about the proportion in which such substances are found in a rich in decaying organic matter. The mixtures e placed in covered vessels, where they lay from to six inches deep, exposed in the shade to the able temperature of summer and winter, and were ingly supplied with rain-water.

he organic matter in No. 1, was composed of grown turnip leaves, which were dried at a perature not exceeding 120°, when they were stituted of—

| | |
|---|---|
| Carbon | 40·14 |
| Hydrogen | 4·98 |
| Oxygen | 33·83 |
| Nitrogen | 3·75 |
| Ashes | 17·30 |
| | 100· |

o. 2. Free grown cabbage leaves, dried at the e temperature, were composed of—

| | |
|---|---|
| Carbon | 36·35 |
| Hydrogen | 6·70 |
| Oxygen | 37·13 |
| Nitrogen | 3·02 |
| Ashes | 16·80 |
| | 100· |

o. 3. *Sea Conferva* (sea-moss, or crow silk) con- ing some particles of sand, dried in the sun, was posed of—

| | |
|---|---|
| Carbon | 31·5 |
| Hydrogen | 5·4 |
| Oxygen | 40·3 |
| Nitrogen | 3·0 |
| Ashes | 19·8 |
| | 100· |

When the experiments had stood for more than two years, scarcely a vestige of the cabbage or turnip leaves was discoverable; traces of the sea conferva were distinguishable on close examination.

To each of these experiments was added as much water as saturated and covered the mixture. On agitation and stirring, in order to dissolve the soluble matter, the miasm which proceeded from all, and especially from the cabbage-leaf experiment, was most offensive: ammonia was also given off to the surrounding atmosphere.

When the water had been on the mixture for two days, the clear liquor was poured off, and passed through filtering paper; that from the

| | | |
|---|---|---|
| Turnip, was .. | 1012·0 | in sp. grav. |
| Cabbage ..... | 1011·4 | „ |
| Sea conferva .. | 1016·8 | „ |

The water of solution was evaporated at a temperature varying from 150° to 200°: there was left from each solution a pasty offensive smelling substance. The constitution of that which proceeded from the

| | | |
|---|---|---|
| Turnip leaves, was.... | Carbon...... | 20·79 |
| „ „ | Hydrogen .. | 6·10 |
| „ „ | Oxygen ..... | 36·98 |
| „ „ | Nitrogen .... | 4·08 |
| „ „ | Ashes ...... | 32·05 |
| | | 100· |

| | | |
|---|---|---|
| Cabbage leaves ...... | Carbon ...... | 15·69 |
| „ „ | Hydrogen ... | 4·32 |
| „ „ | Oxygen .... | 21·41 |
| „ „ | Nitrogen .... | 2·57 |
| „ „ | Ashes ....... | 56·01 |
| | | 100· |

| | | |
|---|---|---|
| Sea conferva........ | Carbon ...... | 25·34 |
| „ „ | Hydrogen .... | 4·79 |
| „ „ | Oxygen ...... | 43·55 |
| „ „ | Nitrogen .... | 3·72 |
| „ „ | Ashes........ | 22·60 |
| | | 100· |

On drawing the same comparison on these results as was drawn on the former, and on taking 100 parts by weight of carbon as the standard, we have in the

| | Carb. | Excess of | | Nitro. | Ashes. |
|---|---|---|---|---|---|
| | | Hydro. | Oxygen. | | |
| Decayed turnip leaves.... | 100· | 9·5 | .. | 19·6 | 154·1 |
| Fresh „ „ | 100· | 3·0 | .. | 9·3 | 43·3 |
| Decayed cabbage leaves.. | 100· | 12·4 | .. | 16·4 | 366·0 |
| Fresh „ „ | 100· | 5·7 | .. | 8·4 | 46·6 |
| Decayed sea conferva.... | 100· | .. | 20·7 | 14·7 | 89·3 |
| Fresh „ „ | 100· | 1·1 | .. | 9·5 | 62·8 |

On comparing the analytical results of these experiments with those at page 201, we find in both an increased excess of hydrogen in the turnip and cabbage-leaf experiments; and an excess of oxygen in that of the sea-moss—a plant, which previously to decomposition, contained an excess of hydrogen.

This increased excess of hydrogen in these cabbage and turnip leaf experiments, is in higher proportion than it was in the former experiments which resembled the rotting of plants on the ground; but in lower proportion than it was in those resembling the decaying of plants on the dunghill. The increase of oxygen in the sea-moss experiment, is very considerably less than it was in that made with the seaweed, which was similarly exposed to the atmosphere, or nearly so, but not mixed with sand and clay.

The proportion of nitrogen and ashes, in the soluble decomposed matter proceeding from the decay of turnip and cabbage leaves, increases in a higher proportion, when the sand and clay are employed, than in the other experiments: and the same appears in the soluble portion of the sea-moss experiment, with respect to the nitrogen. Respecting the ashes on this portion of the sea conferva experiment, we cannot speak with any degree of certainty, because the fresh plants were not entirely free from particles of sand.

Without inquiring into the influence of this soluble putrid matter on the growth of plants, which would be out of place in this part of our research; and leaving it to others to define whether all this soluble substance, separable by cold water from decayed vegetable bodies, or what part of it may be regarded as *humus*,—I shall briefly notice some of its leading characteristics. A large portion of matter, soluble in water, is formed during the putrefaction of vegetable bodies, whether these substances undergo decomposition in large heaps, such as the dunghill, or lie on the surface of the earth, or when they are buried in the soil by the plough. Rain-water passing through any soil saturated with this putrid matter, will take up a quantity equal to, from two to four per cent. of its weight. Therefore, the annual fall of rain, is capable of taking up many times the quantity of organic matter required to furnish all the carbon in the plants which grow upon any land. Miasm,—a body whose constitution we are ignorant of,—is constantly emitted from these solutions, when the temperature is favourable for the growth of plants. Ammonia—constituted of nitrogen and hydrogen,—sometimes in combination with carbonic acid, is, occasionally given off from these solutions; and, though these solutions are more generally alkaline, to chemical tests, a free acid sometimes preponderates. The chemical constitution of the substances obtained by evaporating the superfluous water, appears to vary with the situation in which the vegetable matter was kept when under decomposition; land plants, yield a soluble product, in which hydrogen is generally in excess, while in the product of marine plants oxygen preponderates. When hydrogen is in excessive proportion, an alkali is discoverable on the application of turmeric, or reddened litmus paper: when oxygen is in excess, an acid may be detected by litmus paper. But the constitution of these bodies is so variable, that a change from acid to alkali, and from an excess of oxygen to an excess of hydrogen, is often effected in less than a month. Nitrogen is generally in higher proportion, when compared with the weight of carbon, in the substances which have undergone putrefaction, than in the undecomposed plants, whether these plants be the natural products of the land or the sea. Plants yielding no ammonia, on being boiled in a solution of caustic soda or potassa, give it off copiously on being so treated, when they have become putrescent. The putrefactive fermentation appears to be a process by which some of the solid frame-work of plants, which is not separable by cold water on the fresh plants, is rendered soluble.

## THEORY OF THE PUTREFACTIVE FERMENTATION.

Upon the supposition, that the chemical changes, occurring during the putrefactive fermentation, are worked upon the elements of the organic matter of the water incorporated with it, and of the oxygen of the atmosphere; and that at the conclusion of the process there exists the same weight of each element as at the commencement, it is easy to conceive how these elements, by transposition, change the entire character of a part, or of the whole, of the vegetable matter, incorporated water, and atmospheric oxygen; without being able to prove experimentally the precise nature of the change which has been effected. But our experimental acquaintance with this subject is too limited, and the nature of these changes too complex, to admit of our forming any theory, or theories, by which all the phenomena of the putrefactive process can be explained.

Professor Liebig has, however, endeavoured to reduce this subject to fixed principles. His views are given at considerable length in the work already referred to. The conclusions at which he has arrived, are not derived so much from the results of direct experiment, as from analogy. He divides the subject into two parts. He regards the chemical action which takes place between the oxygen of the atmosphere and the organic body as a process of slow combustion, which he designates by the term *eremacauses;* and he considers that internal process which takes place when organic matter is placed in large heaps, as a process of putrefaction brought about by "transformations consisting of the transpositions of the atoms of two or more complex compounds, by which the elements of both arrange themselves naturally into new products, with or without the cooperation of the elements of water. In this kind of transformations, the new products contain the sum of the constituents of all the compounds which had taken a part in the decomposition."*

The experiments adduced in favour of the process of slow combustion (*eremacauses*) were conducted by M. De Saussure.

De Saussure mixed 36 grains of dried extract from oak wood, with one ounce of water impregmated with carbonic acid gas. This mixture did not change the atmosphere, whose volume was 40 cubic inches, and contained 21 per cent. of oxygen, and an inappreciable proportion of carbonic acid. At the end of fifteen days, a thick pellicle was formed, and the air in the receiver had not changed in volume. It contained 5 per cent. of carbonic acid, and 16 per cent. of oxygen. De Saussure concludes from these results that 2 cubic inches of oxygen gas had disappeared, and had been replaced by the same volume of carbonic acid gas, which, according to Lavoisier, would contain 0·4 of a grain of carbon. The extract from oakwood, from which the experiment had been taken, after desiccation, only weighed 30 grains. It appeared then to have lost 5½ grains of water; but it is possible this water was lost during drying. He then dissolved 36 grains of the dried extract from the oakwood in the same quantity of water as that employed in the preceding experiment; dried at the same temperature, it furnished 34 grains of the dried extract. This mixture only lost 2 grains of water during desiccation. From these results, we learn that the 36 grains of dried extract, had been deprived of half a grain of carbon, by the influence of the oxygen gas under the receiver, and that there had been formed at the same time 3½ grains of water.[*]

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* Liebig, page 247.

The second experiment is probably the one which Liebig more particularly refers to,[†] when he says, "240 parts[‡] of dry saw-dust of oakwood convert 10 cubic inches of oxygen into the same quantity of carbonic acid, which contains 3 parts[§] by weight of carbon; while the weight of the saw-dust is diminished by 15 parts. Hence 12 parts[‖] by weight of water are at the same time separated from the elements of the wood."

Saussure[¶] made a paste with water and half an ounce of saw-dust, from the trunk of an oak dried at a degree of temperature determined by the thermometer. This mixture was put into a glass case for five weeks under a large receiver full of common air, standing over mercury to cut off atmospheric communication, and exposed to an even temperature. During this time, the air did not change in volume; it contained 10 cubic inches of carbonic acid, which had been formed in the place of the same volume of oxygen. This saw-dust was then exposed to the air, under circumstances equally as favourable as when under the receiver. At the end of three weeks, it was dried at the same degree of temperature. It was found to have lost by drying 15 grains. The saw-dust so exposed was covered with a brown surface; 100 parts of this brown surface furnished by carbonization 20½ parts of carbon; 100 parts of the saw-dust, before it was exposed to the air, only furnished 17½ parts of carbon.

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[*] Recherches Chimique sur la Végétation, p. 139.

[†] Organic Chemistry, p. 308.

[‡] Probably 220 grains—half an ounce.

[§] Not 3 grains of carbonic acid—10 cubic inches of carbonic acid comprise only 1·3 grain of carbon.

[‖] The loss in weight, exclusive of the carbon in the carbonic acid, would be (15−1·3=) 13·7 grains.

[¶] Recherches Chimique sur la Végétation, p. 147.

De Saussure observes, that the results obtained from these experiments, and from several others, show us, first, that during the decay of wood it does not assimilate with the oxygen of the atmosphere;—secondly, that oxygen only assimilates with carbon;—thirdly, that these vegetable substances at the same time give off, in the form of water, a great proportion of their oxygen and hydrogen;—fourthly that the taking away of these elements increases the remaining proportion of carbon.

The experiments made with a solution of 34 grains of the *dry* extract, which would contain about half its weight of carbon, furnished, after fifteen days' exposure to a limited atmosphere, 2 cubic inches of carbonic acid, comprising ·26 of a grain of carbon.

The second experiment upon 220 grains of dry saw-dust, comprising about 105 grains of carbon, furnished in five weeks, on being kept in a confined atmosphere, 10 cubic inches of carbonic acid, containing 1·3 grain of carbon.

The weight of carbon in these volumes of carbonic acid, when compared with that in the substances subjected to experiment, is—

| | | |
|---|---|---|
| For that in the extract .... | 1·53 | per cent. |
| „ „ sawdust .... | 1·24 | „ |

If these experiments had been kept for a much longer period, under the same favourable circumstances for undergoing chemical changes, from 70 to 80 per cent. of their carbon would have disappeared during this process of decay or putrefaction. The weight of carbon in the carbonic acid resulting from these two experiments, forms about 3 per cent. only of that which would have disappeared under a complete process of putrefaction. Therefore any theory based upon these results, may be considered as resting upon a very small and imperfect foundation.

By a further examination of the results of these experiments, we are led to suspect that a portion of carbon disappears, by a process unknown to us, during the decay and putrefaction of vegetable matter.

When organic bodies are exposed to the atmosphere, those portions which are most favourably circumstanced for putrefactive fermentation, which may be one, five, ten, or any other proportion, are the first to be acted upon; afterwards other portions of the organic matter, less favourably situated; to the exclusion of the rest, which remains in its original condition.

This would be the case in the two experiments under consideration. The extreme quantity of the dry extract acted upon would be from 20 to 25 per cent.; and that of the sawdust from 10 to 15 per cent. Say, not exceeding 8 grains of the former, and 30 of the latter; leaving 26 grains of the dry extract, and 190 of the sawdust in *statu quo.*

The loss in weight during drying was for—

| | |
|---|---|
| The extract exposed .......... | 6 grains |
| „ „ not exposed........ | 2 „ |

leaving hydrogen and oxygen (water), separable by drying, 4 grains, formed by ·26 grains of carbon entering into and passing off as carbonic acid.

If all the carbon existed in the experiment at the end of the fifteen days, which it originally contained, the quantity would be found, on the fifteenth day, as under:—

| | | |
|---|---|---|
| In the 26 grains not acted upon | 13·00 | grains carbon |
| „ carbonic acid gas | ·26 | „ |
| „ 8 grains acted upon | 3·74 | „ |
| | 17· | „ |

On the 8 grains of extract chemically acted upon parting with 4 grains of water, by drying, the remaining substance is constituted of—

| | | |
|---|---|---|
| Carbon | 3·74 | 93·5 |
| Hydrogen and oxygen | ·26 | 6·5 |
| | 4· | 100· |

The experiment with 220 grains of sawdust, after being kept in a confined atmosphere for five weeks, yielded 10 cubic inches of carbonic acid. On allowing three-fifths of this volume to have been formed and given off during the three weeks it was fully exposed to the atmosphere, previously to its being dried, the carbon in the carbonic acid given off in the two periods would be 16 cubic inches, containing 2 grains of carbon.

It may be observed, that the sawdust, not being in solution, the chemical action would not extend itself over so high a proportion of this body, as over the soluble extract; and that 30 grains may be regarded as an extreme quantity, which would, at the commencement, contain about 15 grains of carbon.

The chemical change effected upon the 30 grains of sawdust, gave rise to the formation of—

| | | |
|---|---|---|
| Water | 13 | grains. |
| Carbon in carbonic acid | 2 | „ |
| | 15 | „ |

leaving for the weight of the body on which the chemical action had passed, 15 grains; which, if all the carbon existed in the experiment, after the exposure, which it comprised before, would be constituted of—

| | | |
|---|---|---|
| Carbon | 13 | 86·7 |
| Hydrogen and oxygen | 2 | 13·3 |
| | 15 | 100· |

By carbonization, Saussure found the proportion of charcoal resulting from the sawdust, and the brown surface formed during decay, was, from the sawdust, 17·5 per cent.; from the brown surface, 20·5 per cent. If this were a correct mode of determining the proportional weight of carbon, and if no carbon were removed by any other process than carbonization, the charcoal resulting from the brown surface, instead of being 20·5 per cent., ought to have formed (50 : 86·7 : : 17·5 :) 30·3 per cent. of its weight; making the proportionate weight of the—

| | |
|---|---|
| Charcoal found by experiment | 100 |
| „ „ „ calculation | 144 |

The question is, By what process have these 44 parts of charcoal been removed? Until this question is answered, any theory upon the chemistry of the putrefactive process must be merely speculative.

Professor Liebig, as we have already observed, has called in the aid of analogy in theorizing upon this subject. He has taken more particularly for his guide, certain theories upon the chemical changes which accompany the vinous and the acetous fermentations. These theories are unsatisfactory, as regards their immediate object; and therefore furnish no analogy which can be properly applied to another.

## CARBON DISAPPEARS WHEN SEEDS GERMINATE AND GROW IN A CONFINED ATMOSPHERE.

The first experiment to be described, which favours this conclusion, was made with 50 grains by weight (60 seeds) of red wheat, constituted of—

| | |
|---|---|
| Carbon | 19·48 |
| Hydrogen | 3·42 |
| Oxygen | 25·63 |
| Nitrogen | ·61 |
| Ashes | ·86 |
| | 50· |

These were steeped in distilled water for 30 hours, and afterwards arranged round the side of a watch glass, in the centre of which was distilled water. The watch glass was placed upon mercury, and covered with a tall jar, whose content was 155 cubic inches. So much atmospheric air was drawn out as made the volume in the jar, at 30° barometer and 60° temperature, 122 cubic inches.

This experiment was kept in the shade, and at a temperature varying from 60° to 70°, for eighty-nine days. The seeds all germinated and grew, until many of them were nearly three inches in length. After the first thirty-six days, the colour of the leaves began to change from light green to pale yellow; and became covered with spots of blue mould, and patches of white down.

On the eighty-ninth day, the volume of air in the jar, at 30° barometer, and 60° temperature, was 144 cubic inches. Six separate portions of this air were examined over mercury, which gave, for the volume of carbonic acid, 29·9 cubic inches. The young plants, which were all dead, and had lost many of their leaves, were, together with the water in the experiment, put on a glass plate, standing on mercury, by the side of which was a vessel containing sulphuric acid; and over the whole was inverted a bell-glass, dipping in the mercury. In this situation the experiment remained, until all the water was taken up by the acid, and the dead plants, husks, and roots, brought to a powderable state of dryness. During this desiccating process, four cubic inches of carbonic acid was given off, making the entire volume of carbonic acid in the experiment, 33·9 cubic inches, comprising 4·43 grains of carbon.

The plants, roots, and husks, weighed, when dry, 30·2 grains, to which may be added ·2 of a grain, for that vegetable matter which imparted a little colour to the sulphuric acid, making the weight of the mixture analyzed, 30·4 grains, constituted of—

| | | |
|---|---|---|
| Carbon .... | 39·04...... | 11·87 |
| Hydrogen .. | 6·62...... | 2·01 |
| Oxygen .... | 49·09...... | 14·93 |
| Nitrogen .. | 2·35...... | 0·71 |
| Ashes ...... | 2·90...... | 0·88 |
| | 100· | 30·4 |

On a recapitulation of the carbon in this experiment, we have—

| | |
|---|---|
| Carbonic acid gas ...... | 4·42 |
| Plants, roots, and husks .. | 11·87 |
| Total...... | 16·30 |
| Wheat seeds ............ | 19·48 |
| Deficiency of carbon | 3·18 grs. |

equivalent to 16·33 per cent.

Another experiment, similarly conducted in many respects, was made with 120 seeds of the wheat, weighing 100 grains. These were kept in distilled water, at a temperature varying from 50° to 55° for 36 hours; afterwards placed on a watch glass, standing on mercury, and covered with a tall jar. So much air was drawn out as made the volume within the jar at 30° and 60°: 168 cubic inches constituted of —

| | |
|---|---|
| Nitrogen .............. | 132· |
| Oxygen ................. | 35·2 |
| Carbonic acid .......... | 0·8 |
| | 168· |

The seeds all germinated and grew, but never had a very healthy appearance. The colour of the plants, whose length was from one to three inches, was green; their roots white and slender. Many of the roots stretched over the watch-glass, and were in contact with the water which covered the mercury. The sides of the inverted jar were covered with moisture and small drops of water, during the entire period of the experiment. The atmosphere within the jar was never changed. A small quantity of water was introduced three times, by means of a *peppin.*

On the thirty-third day, some of the plants had a sickly appearance. The volume of the atmosphere within the jar, at the same barometric pressure and temperature, was reduced to 164·7 cubic inches. Six samples of air were drawn out and examined, first, for carbonic acid, of which the following is an account.

Volume in cubic inches of air drawn out—

| | At first. | After removing Carb. Acid. | Carb. Acid. |
|---|---|---|---|
| No. 1, | ·538 | ·458 | ·080 |
| ,, 2, | ·522 | ·443 | ·079 |
| ,, 3, | ·559 | ·480 | ·079 |
| ,, 4, | ·575 | ·497 | ·084 |
| ,, 5, | ·381 | ·325 | ·056 |
| ,, 6, | 1·41 | 1·215 | ·205 |

giving for the volume per cent. of carbonic acid in—

| | |
|---|---|
| No. 1, | 14·85 |
| ,, 2, | 15·13 |
| ,, 3, | 14·14 |
| ,, 4, | 14·61 |
| ,, 5, | 14·70 |
| ,, 6, | 14·48 |
| Mean.... | 14.64 |

and for the volume of this gas in the jar, 24·1 cubic inches, comprising 3·15 grains of carbon.

After removing the carbonic acid by liquor potassa, the air in Nos. 1 to 4, were washed in water, and their oxygen removed by phosphorus. The volume of nitrogen left, was in—

| | | |
|---|---|---|
| No. 1, | ·395 | cub. inch. |
| ,, 2, | ·378 | ,, |
| ,, 3. | ·415 | ,, |
| ,, 4, | ·435 | ,, |

which give, for the constitution of the air within the jar, at the conclusion of the experiment—

| | No. 1. | No. 2. | No. 3. | No. 4. |
|---|---|---|---|---|
| Carbonic acid | 14·85 | 15·13 | 14·14 | 14·61 |
| Oxygen | 10·09 | 10·26 | 10·04 | 9·63 |
| Nitrogen | 75·06 | 74·61 | 75·82 | 75·76 |
| | 100· | 100· | 100· | 100· |

shewing that the volume of oxygen gas, when added to that in the carbonic acid, exceeds the proportion of oxygen found in the surrounding atmosphere, and the proportion of nitrogen considerably diminishes.

The plants, roots, husks, and undecomposed flour, on drying over sulphuric acid, gave off 1·8 cubic inches of carbonic acid, comprising ·23 of a grain of carbon. The acid was not changed in colour during the process of desiccation. When the vegetable bodies were brought to that state in which they were analyzed they weighed 75·8 grains, and were constituted of—

| | | |
|---|---|---|
| Carbon | 37·75 | 28·61 |
| Hydrogen | 6·59 | 4·99 |
| Oxygen | 50·48 | 38·27 |
| Nitrogen | 3·02 | 2·29 |
| Ashes | 2·16 | 1·64 |
| | 100· | 75·8 |

On a recapitulation of the products of this experiment, we have—

| | Carbon. | Hydr. | Oxy. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| Plants, husks, &c. | 28·61 | 4·99 | 38·27 | 2·29 | 1·64 | 75·8 |
| Carbonic acid gas | 3·15 | .. | 8·8 | .. | .. | 12·2 |
| Ditto ditto | ·23 | | | | | |
| Total | 31·99 | 4·99 | 47·07 | 2·29 | 1·64 | 88·0 |
| In the Seeds | 38·96 | 6·84 | 51·26 | 1·22 | 1·72 | 100· |
| | –6·97 | –1·85 | –4·19 | +1·07 | –·08 | –12· |

giving a loss of 6·97 grains of carbon, equal to 17·89 per cent.

The next experiment to be described, which was conducted upon a somewhat different principle, shews, on a recapitulation of the products, a still greater loss of carbon. It was made on the 25th of April, with 300 grains (396 seeds) of the same sample of wheat, which, after being in distilled water for thirty-six hours, was put into a retort, whose beak was graduated into cubic inches, with as much water as made the whole 550 grains, making the experiment constituted of—

| | |
|---|---|
| Carbon | 116·88 |
| Hydrogen | 81·63 |
| Oxygen | 642·67 |
| Nitrogen | 3·66 |
| Ashes | 5·16 |
| | 850· grs. |

The content of the body of the retort, was sixty, and that of the beak thirty cubic inches. The beak of the retort was placed in mercury, and kept in the shade, at a temperature varying from 58° to 70°. The seeds germinated and grew, until the leaves were four inches in length. When the experiment had stood for seventy days, spots of blue mould were upon the husks of the seeds, and the leaves of the plants were covered with white down. At this period, the whole had the appearance of passing rapidly into decay,—an appearance which continued till the 27th of November, when the experiment was broken up.

The atmosphere of the retort was changed eight times, by first removing the carbonic acid by liquor potassa, and afterwards introducing fresh atmospheric air, by blowing into the retort with a pair of bellows. The entire volume of carbonic acid removed, was 139·5 cubic inches.

The retort was emptied of its contents, which were highly putrescent: the seeds had lost their original appearance, and the leaves their shape. The whole was dried at a temperature not exceeding 120°, and allowed to acquire the hygroscopic state of the atmosphere, when the weight was 75·6 grains. In this condition it was reduced to a powder, analyzed, and found to be constituted of —

| | | |
|---|---|---|
| Carbon | 38·05 | 28·80 |
| Hydrogen | 6·35 | 4·77 |
| Oxygen | 46·38 | 35·07 |
| Nitrogen | 3·02 | 2·28 |
| Ashes | 6·20 | 4·68 |
| | 100· | 75·6 |

The carbonic acid would be constituted of—

| | | |
|---|---|---|
| Carbon | 18·24 | grains |
| Oxygen | 47·7 | do. |

The principal part of this 47·7 grains of oxygen would be atmospheric oxygen; on adding it, to the weight of that element, in the seeds, and in the water, we have the total weight of the oxygen in the experiment 690·37 grains.

If, on a recapitulation of the products of this experiment, we allow for the volume of gas constituted of carbon and hydrogen after the rate of five per cent. of the volume of carbonic acid, a proportion in all probability far exceeding the real one, the volume of this gas in the experiment would be 7 cubic inches, constituted of —

| | | |
|---|---|---|
| Carbon | 1·91 | grains. |
| Hydrogen | ·33 | do. |

Supposing that the deficiency of (3·36—2·28=) 1·38 grains of nitrogen, passed off as ammonia, it would be combined with ·24 of a grain of hydrogen, making 1·62 grain of ammonia.

On comparing the weight of the ultimate elements, thus sought out of the experiments, with their weight at the commencement, including the atmospheric oxygen, we have in the

| | Carbon. | Hydro. | Oxygen | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| Powdered plants, husks, &c....... | 28·80 | 4·77 | 35·07 | 2·28 | 4·68 | 75·6 |
| Carbonic acid gas .. | 18·24 | .. | 47·70 | .. | .. | 65·94 |
| Carburetted hydrogen | 1·91 | ·33 | .. | .. | .. | 2·24 |
| Ammonia .......... | .. | ·24 | .. | 1·38 | .. | 1·62 |
| Water making up the original weight | .. | 83·7 | 669·6 | .. | .. | 753·3 |
| Total ...... | 48·95 | 89·04 | 752·37 | 3·66 | 4·68 | 898·7 |
| Seeds, water, and oxygen, from atmosphere ..... | 116·88 | 81·63 | 690·37 | 3·66 | 5·16 | 898·7 |
| Increase ... | .. | 7·41 | 52·0 | .. | .. | .. |
| Decrease ... | 67·93 | .. | .. | .. | ·48 | .. |

Per Cent.
These give a loss of 57·3 of carbon in the experiment.
,, a gain of 8·9 of hydrogen ,,
,, a gain of 7·7 of oxygen ,,

And on calculating for the weight of the hydrogen and oxygen comprised in the seeds only, the increase of—

Hydrogen is ...........35·6 per cent.
Oxygen ...............29·5 ,,

In the next experiment the gaseous products were allowed to escape without recognition. It was prepared on 8th of May 1836 with 1,460 grains of steeped barley, in the preparation of which 1,000 grains of very dry barley had been employed. The barley yielded by analysis—

| | |
|---|---|
| Carbon | 43·93 |
| Hydrogen | 6·49 |
| Oxygen | 46·28 |
| Nitrogen | 1·95 |
| Ashes | 1·35 |
| | 100· |

On calculating for the 460 grains of water which the barley had absorbed, we have the experiment constituted of—

| | |
|---|---|
| Carbon | 439·3 |
| Hydrogen | 116·0 |
| Oxygen | 871·7 |
| Nitrogen | 19·5 |
| Ashes | 13·5 |
| | 1460· |

These were placed in a bottle, content 58 cubic inches, into the neck of which was ground a tube eighteen inches in length, bent four times at right angles, and which had a bore one-tenth of an inch in diameter, through which atmospheric communication was kept up during the time the materials were under experiment.

The seeds almost all germinated, and in three weeks the whole was one mass of roots, short stems, and husks, and in five weeks appeared to be in a state of decay. In six months the young plants had entirely lost their green colour, and the whole mass began to turn black.

Thus circumstanced, the experiment stood on a table, where it was seldom moved, and at a temperature varying with the different seasons, until the

25th of January, 1840, when it was examined. The apparatus had lost 46 grains in weight. It was emptied of its contents, which were in a semifluid state, and very ill flavoured, and when dried at 130° weighed 625 grains, and constituted of—

| | | |
|---|---|---|
| Carbon | 285·7 | grains. |
| Hydrogen | 45·4 | „ |
| Oxygen | 262·2 | „ |
| Nitrogen | 18·1 | „ |
| Ashes | 13·6 | „ |
| | 625· | „ |

And upon the supposition that it was water only which passed off during desiccation, the constitution of the semifluid body would be—

| | | |
|---|---|---|
| Carbon | 285·7 | grains. |
| Hydrogen | 133·1 | „ |
| Oxygen | 963·5 | „ |
| Nitrogen | 18·1 | „ |
| Ashes | 13·6 | „ |
| | 1414· | |

On comparing the weight of these elements with that of those at the commencement, we have—

| | Carbon. | Hydr. | Oxygen. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| 1836—May 8th, | 439·3 | 116·0 | 871·7 | 19·5 | 13·5 | 1460· |
| 1840—January 25th, | 285·7 | 133·1 | 963·5 | 18·1 | 13·6 | 1414· |
| Increase, | .. | 17·1 | 91·8 | .. | ·1 | .. |
| Decrease, | 153·6 | .. | .. | 1·4 | ·0 | 46· |

Showing a loss of 34·9 per cent. of carbon.
„ a gain of 14·8 „ of hydrogen.
„ „ 10·5 „ of oxygen.

And if we calculate for the weight of the hydrogen and the oxygen in the dry seeds, we have the increase upon the original weight—

| | | |
|---|---|---|
| Of the hydrogen | 26·3 | per cent. |
| „ oxygen | 19·9 | „ |

The decrease in the weight of the carbon, as shown in this comparison, appears greater than it really was in the experiment. A part of that 46 grains which the experiment lost in weight during its continuance, would be carbon, which would pass off as carbonic acid. If we take the most extreme case, and regard this loss in weight as pure carbon, removed by means of atmospheric oxygen, in the shape of carbonic acid, we reduce the loss in the weight of carbon to 107·6 grains, equal to 24·5 per cent.

In these experiments the loss of carbon is not more apparent than the gain of hydrogen and oxygen, disposing us to infer, that when seeds germinate, grow, and decay, in limited atmospheres, some chemical changes take place, by which the carbon is converted into hydrogen and oxygen.

### CARBON DISAPPEARS WHEN MIXTURES OF ORGANIC MATTER UNDERGO PUTREFACTION.

The experiments selected for proving that carbon undergoes decomposition during the putrefactive fermentation of mixed bodies, were each made with 50 grains of wheat straw, cut into small pieces, and constituted of—

| | |
|---|---|
| Carbon | 19·86 |
| Hydrogen | 3·30 |
| Oxygen | 25·73 |
| Nitrogen | ·45 |
| Ashes | ·66 |
| | 50· |

5 grains of turnip leaves, in a state of powder, and which had undergone partial putrefaction, constituted of—

| | |
|---|---|
| Carbon | 1·69 |
| Hydrogen | ·33 |
| Oxygen | 1·86 |
| Nitrogen | ·21 |
| Ashes | ·91 |
| | 5· |

And 300 grains of urine, constituted of—

| | |
|---|---|
| Carbon | 2·61 |
| Hydrogen | 32·42 |
| Oxygen | 259·51 |
| Nitrogen | 2·16 |
| Ashes | 3·30 |
| | 300· |

These were put into small wide-necked bottles, standing upon lamp glasses, which raised them about three inches above the level of the mercury employed for cutting off atmospheric communication. The two experiments were so similarly conducted, that one description will suffice for both.

A graduated glass jar, 16 inches deep, content 71 cubic inches, was inverted over the experiment, and rested on a plate containing mercury. On drawing out from six to seven cubic inches of air, the mercury in the inside of the jar, was more than an inch above that on the outside.

This experiment was fitted up on the 26th February. For the first sixteen days, it stood where the temperature varied from 48° to 64°. Afterwards the variation of temperature was from 54° to 74°.

The straw began to assume a dark colour on the second day, and continued to grow deeper in colour until the final examination, when it was dark brown. At each time the experiment was readjusted, and previous to its gaseous contents being examined, the necessary observations and calculations were made for reducing the volume of the air, to its volume at 30° barometer and 60° temperature. The air within the jar was examined by first introducing liquor potassa, which remained in the jar for five or six hours before the remaining volume of gas was noted. Several portions of the gaseous contents were then removed, and further tested for carbonic acid; afterwards for oxygen, and carburetted hydrogen.

In the first column of the following table, is set down the change in the volume of the atmosphere, within the jar, effected by the materials under experiment. In the second, the volume of carbonic acid removed by liquor potassa.

| Date. | | Diminution in Volume. Cubic inches. | Volume of Carbonic Acid. Cubic inches. |
|---|---|---|---|
| Feb. | 26 | .. | .. |
| March | 5 | 2·21 | 1·8 |
| „ | 13 | 1·82 | 2·1 |
| „ | 24 | ·63 | 3·9 |
| April | 10 | ·44 | 2·7 |
| „ | 26 | ·46 | 2·8 |
| May | 10 | ·32 | 3·3 |
| June | 8 | ·36 | 3·8 |
| | | | 20·4 |

cubic inches of carbonic acid, including that in the jar, at each time the experiment was readjusted. On drying the partially decomposed organic matter over sulphuric acid, 3·6 cubic inches of carbonic acid were given off; making the entire volume of carbonic acid 24 cubic inches, comprising 3·13 grains of carbon.

The partially dried mixture, whose weight was 58·4 grains, on being reduced to a powder and analyzed, gave—

| | | |
|---|---|---|
| Carbon | 32·75 | 19·14 |
| Hydrogen | 6·38 | 3·73 |
| Oxygen | 50·75 | 29·64 |
| Nitrogen | 1·52 | ·87 |
| Ashes | 8·60 | 5·02 |
| | 100· | 58·4 |

Samples of air, taken from the jar after the removal of the carbonic acid, March 5th, 13th, and 24th, and tested with muriate of platinum, and a gentle heat, gave no indications of carburetted hydrogen. And samples taken April 10th and May 10th, on being tested for oxygen, by phosphorus, gave results which favoured the inference, that the principal part of the carbonic acid had been formed at the expense of atmospheric oxygen. These results indicate that the carbon resulting from this experiment, was comprised principally in the carbonic acid gas and the partially dried powder; and that the loss in weight would, for the most part, be water, holding in solution a small portion of ammonia. On making our calculation for this loss being water only, we have to add, to the weight of the hydrogen and oxygen in the portion analyzed, 32·61 grains of the former, and 260·86 of the latter.

On comparing the weight of each element, at the commencement of the experiment, with that at the conclusion, we have—

| | | Car. | Hyd. | Oxy. | Nitro. | Ash. | Total. |
|---|---|---|---|---|---|---|---|
| June 8. | Carbonic acid .... | 3·13 | .. | .. | .. | .. | 3·13 |
| | Powder ........ | 19·14 | 3·73 | 29·64 | ·87 | 5·02 | 58·40 |
| | Water .......... | .. | 32·61 | 260·86 | .. | .. | 293·47 |
| | Total........ | 22·27 | 36·34 | 290·50 | ·87 | 5·02 | 355· |
| Feb. 26. | —Straw, &c... | 24·16 | 36·05 | 287·10 | 2·82 | 4·87 | 355· |
| | Increase .... | .. | ·29 | 3·4 | .. | ·15 | .. |
| | Decrease .... | 1·89 | .. | .. | 1·95 | .. | .. |

Showing a loss of carbon equal to 7·8 per cent.; and a gain of oxygen of about 11·0, and of hydrogen of about 8 per cent., upon the dry materials; without taking into calculation the hydrogen which would pass off in combination with nitrogen, forming ammonia.

The other experiment was conducted upon similar principles, under a tall jar: content, 62 cubic inches. This was under experiment nineteen months. At twenty-two different examinations 44·1 cubic inches of carbonic acid was removed, comprising 5·99 grains of carbon. After the first six months, the decomposing body was covered with blue mould, which continued till the last. It was supplied four times with water, which kept the materials in a proper state of moisture for undergoing decomposition. When finally examined, its colour under the mould was dark brown, inclining to blackness. No carbonic acid was given off in preparing it for analysis by drying over sulphuric acid; neither was the acid coloured. Its weight, when analysed, was 36·4 grains, constituted of—

| | |
|---|---|
| Carbon ................ | 11·50 |
| Hydrogen .............. | 2·80 |
| Oxygen ................ | 15·49 |
| Nitrogen .............. | ·93 |
| Ashes .................. | 5·68 |
| | 36·4 |

About 24 per cent. of its weight was soluble in cold water; the rest appeared to be undecomposed wheat straw. Its smell resembled that of farm-yard manure in a decomposed state.

On a recapitulation of the element, we have—

| | Car. | Hyd. | Oxy. | Nitro. | Ash. | Total. |
|---|---|---|---|---|---|---|
| At the end of 19 months— | | | | | | |
| Carbonic acid .. | 5·99 | .. | .. | .. | .. | 5·99 |
| Dry mixture.... | 11·50 | 2·8 | 15·49 | ·93 | 5·68 | 36·4 |
| Total...... | 17·49 | 2·8 | 15·49 | ·93 | 5·68 | 42·39 |
| At the commencement | 24·16 | 36·05 | 287·11 | 2·82 | 4·87 | 355· |
| Decrease .. | 6·67 | 33·25 | 272·62 | 1·89 | .. | 312·61 |
| Increase .. | .. | .. | .. | .. | ·81 | .. |

shewing a loss of carbon equal to 27·3 per cent., with a gain in the weight of the hydrogen and oxygen corresponding with that in the former experiment.

## CARBON DISAPPEARS DURING THE PUTREFACTION OF SEEDLING PLANTS.

The experiment to be described under this head, is one which is easily conducted, and proves that a portion of that element (carbon) which gives solidity to vegetable bodies, disappears when the plants undergo decomposition. It was made with 640 grains of the roots, stems, and leaves of seedling wheat plants; which, together with 160 grains of water, were put into a strong five-ounce bottle, which was very tightly corked, and the cork sealed over. A similar weight, of precisely the same sample of seedling plants, was dried at a temperature not exceeding 130°. These, in their dry condition, were also put into a bottle, which was tightly corked, and kept in a dry place. The sealed bottle was accurately weighed, and kept for nearly three years, at a temperature varying from 60° to 95°. The loss in weight during the first six months was not 1 grain; in the first twelve months, 3 grains; in the second year, the loss in weight was 2 grains; and the total loss in gross weight, at the final examination, was 9 grains.

On drawing the cork, there was no escape of gas; the presence and escape of which, in many experiments of this kind, renders them of little or no value in testing the principle under consideration. The odour proceeding from this experiment was not so noxious as that which proceeded from similar experiments, made with turnip and cabbage leaves. The plants had changed in colour, from dark green to light brown. They were emptied out of the bottle, and immediately spread on a plate, standing over a vessel holding 2 lbs. of sulphuric acid. The whole was covered with a bell-glass, kept at a temperature not exceeding 100°; damp atmospheric communication being cut off by hot lime, placed round the exterior of the bottom of the bell-glass. During desiccation, the plants became much darker in colour; 6·8 cubic inches of carbonic acid were formed; and in two days they were brought to a powderable state of dryness.

The sulphuric acid was as much darkened in colour as it would have been by the addition of a quarter of a grain of sugar. The plants in their dry state weighed 162·3 grains; and after exposure to the atmosphere for twenty-four hours, their weight was increased to 166 grains. The counter part, which had been kept, in the dry condition, in the corked bottle, weighed, on being exposed during the same period, 226·4 grains.

In comparing the weight of the carbon contained in the organic body, which had undergone chemical change, with that in the bottle that had undergone no such change, we must regard the former (the two being equally dry) as comprising from one to four per cent. more of this body than the latter.

The two samples, after having been exposed to the atmosphere for twenty-four hours, gave

| | Carbon. | Hydr. | Oxygen. | Nitro. | Ashes. | Total· |
|---|---|---|---|---|---|---|
| The undecomposed dry plants ............ | 90·48 | 15·24 | 107·64 | 7·64 | 5·4 | 226·4 |
| The plants which had undergone decomposition | 67·74 | 12·39 | 74·25 | 6·36 | 5·26 | 166· |
| Being a decrease of.... | 22·74 | 2·85 | 33·49 | 1·28 | ·14 | 60·4 |

From this loss of 22·74 grains of carbon must be deducted that in the 6·8 cubic inches of carbonic acid given off during desiccation, which reduces the decrease of carbon to 21·86 grains, equivalent to 24·2 per cent. upon that originally contained in the experiment.

On taking the most extreme case, and supposing that the loss in weight sustained by the materials under experiment was pure carbon, we, in such a case, reduce the loss of carbon in the experiment to 12·86 grains, 14·2 per cent.; and on carrying out this supposition we have, in the materials which underwent decomposition, the hydrogen and oxygen as under,—viz.

| | | Grains. | grains. |
|---|---|---|---|
| Hydrogen | In the compound analyzed | 12·39 | 18·23 |
| | Ditto ammonia ....... .. | ·27 | |
| | Ditto water lost by drying | 5·57 | |
| Oxygen | In the compound analyzed | 74·25 | 118·8 |
| | Ditto water lost by drying | 44·55 | |

Shewing an increase of that in the dry plants of

Hydrogen equal to 19·6 per cent.
Oxygen „ 10·3 „

## CARBON DISAPPEARS WHEN FRUIT UNDERGOES PUTREFACTION.

Another simple mode of experimenting to prove that carbon disappears during the putrefactive fermentation; is to place the organic matter in an open vessel, above another vessel holding hot lime, and water, mixed in such proportions as to form a thin paste, or thick lime water; and cover the whole with an air-tight vessel, resting upon a plate, cutting off external atmospheric communication with a small quantity of water.

If the organic body be one which readily undergoes decomposition, the atmosphere may be changed every day; if not, once in every two or three days will be sufficient. On stirring the lime-water at each time the atmosphere is changed; the carbonic acid given off by the putrifying body is immediately removed, and forms a thin film of carbonate of lime.

At the conclusion of the experiment, the proceeds may be collected by first placing all the lime employed in a bottle, then adding a sufficient quantity of dilute muriatic acid to take up all this lime, stopping the bottle with dry cotton wool, and noticing the loss in weight occasioned by the acid's decomposing the carbonate of lime, and setting the carbonic acid free, which will pass off in a partially dry state through the dry cotton-wool, holding 27·6 per cent. of its weight of carbon, the principal part of which must have proceeded from the organic matter under experiment. The carbon in the undecomposed part of the organic body, together with that in the less volatile and new-formed bodies may be determined in the manner described under the last head.

The following is an account of an experiment, conducted in many respects in the manner above-mentioned. It was made with 500 grains of a bruised summer apple, in a porcelain dish, supported by two pieces of glass laying over another dish which contained 500 grains of lime, mixed with nearly 2000 grains of water. These were covered with a bell-glass, content 400 cubic inches, dipping in water which cut off atmospheric communication. The experiment was fitted up on the 23d of August. The atmosphere in the bell-glass was changed three times a-week; and at each time, the mixture of lime and water was stirred. The putrefaction, without any signs of the vinous fermentation, commenced from the first, and continued to the end of the experiment. The experiment stood where the temperature varied from 60° to 75°, till Nov. 3. At this time, it was covered with blue mould, under which was a pulpy mass, which emitted a very offensive odour. The porcelain dish holding the lime and water was replaced by a glass holding near two pounds of sulphuric acid; and atmospheric communication, instead of being cut off by water, was now cut off by mercury, and the whole kept at a temperature not exceeding 55°, until the decomposed organic matter was so dry as to be easily reduced to a powder, when it weighed 24·8 grains, and was constituted of

| | | |
|---|---|---|
| Carbon | 35·3 | 8·75 |
| Hydrogen | 7·3 | 1·81 |
| Oxygen | 48·4 | 12·01 |
| Nitrogen | 3·5 | ·87 |
| Ashes | 5·5 | 1·36 |
| | 100· | 24·8 |

The carbonic acid was expelled from the lime, and its quantity determined by weight, in an apparatus to which was attached a tube containing dry chloride of calcium. The lime and water were first put into this apparatus; afterwards, an excessive quantity of muriatic acid. After all the lime had been acted upon by the acid, the apparatus was kept at a high temperature, with a view to depriving the liquor of its carbonic acid. On the following day the apparatus had lost 54 grains in weight of carbonic acid gas, comprising 14·8 grains of carbon.

Five hundred grains, an exact counter-part sample, from the same apple, were dried at 120° to 150°, on the 23d August, when the weight was 98 grains, constituted of

| | Grains. | Grains. |
|---|---|---|
| Carbon | 36·1 | 35·38 |
| Hydrogen | 6·8 | 6·66 |
| Oxygen | 53·0 | 51·94 |
| Nitrogen | 2·1 | 2·06 |
| Ashes | 2·0 | 1·96 |
| | 100· | 98· |

These, on a recapitulation of the carbon, gave in the

| | | |
|---|---|---|
| Dry putrid body | 8·75 | grains of carbon. |
| Carbonic acid gas | 14·8 | |
| Total | 23·55 | |
| The fresh apple | 35·38 | |

Shewing a loss of..11·83 grains, equal to 33·4 per cent. without making any allowance for that in the bell-glass, when fresh atmospheric air was introduced.

## CARBON DISAPPEARS DURING THE PUTREFACTION OF HERBACEOUS PLANTS.

Most succulent herbs form good subjects for testing the disappearance of carbon during the putrefactive fermentation, if that process commences at the first. But it very frequently happens, that a fermentative process, which has for one of its products carbonic acid formed independently of atmospheric oxygen, first takes place; a process, which we can scarcely designate putrefaction; and one which, like the vinous fermentation, is accompanied with little or no loss in the weight of the carbon employed. When this is the case, so much of the carbon passes off by this process, that when putrefaction really commences, a part only of that carbon which was at first comprised in the organic matter is present; hence it follows, that such experiments exhibit but small differences, between the weight of the carbon in the bodies subjected to experiment, and that, in the products resulting from the various chemical actions.

The following is an account of an experiment made with cabbage-leaves, which appeared to undergo putrefaction from the first. It may be looked upon as conveying an idea of the nature of that change, which takes place when vegetable matter of this kind is allowed to rot in the ground. It was made with 1000 grains of the interior leaves of a full grown cabbage, which were cut into small pieces. Another portion, of equal weight of the leaves, was dried in thirty-six hours, and afterwards allowed to attract moisture from the atmosphere for twenty-four hours, when its weight was 136 grains, and constituted of—

| | | |
|---|---|---|
| Carbon | 31·6 | 42·9 |
| Hydrogen | 7·4 | 10·1 |
| Oxygen | 52·7 | 72·2 |
| Nitrogen | 2·5 | 3·4 |
| Ashes | 5·8 | 7·4 |
| | 100· | 136· |

These fresh cut leaves, together with 50 grains of putrid liquor, were put into an open vessel resting upon a plate holding mercury; over them was laid a finely graduated tube, and the whole was covered with an inverted jar, content 206 cubic inches, resting in the mercury. The experiment was kept at a temperature not varying more than 2 degrees above or below 60° from November 28th, to the 22nd of February following.

The constitution of the atmosphere within the jar was determined by first examining, for carbonic acid, and afterwards for oxygen and carburetted hydrogen, portions of the air extracted, as also that in the graduated tube kept within the jar, and the following are the results:—

| | Carbonic Acid. | |
|---|---|---|
| Dec. 2 | 22·2 cub. in. | Carb. acid and oxy. 20 per cent. of the volume. |
| 10 | 16·7 „ | Colour changed from white to brown. |
| 24 | 14·1 „ | Carburetted hydrogen not appreciable. |
| Jan. 2 | 7·1 „ | Carb. acid and oxy. 20 per cent. of the volume. |
| 12 | 11·5 „ | |
| 18 | 9·4 „ | Added a portion of water. |
| 25 | 8·9 „ | Carb. acid and oxygen 20·5 per cent. of the vol. |
| Feb. 1 | 6·5 „ | Every appearance of cabbage has disappeared. |
| 8 | 5·8 „ | Carburetted hydrogen not appreciable. |
| 15 | 4·1 „ | Carb. acid and oxy. 20 per cent. of the volume. |
| 22 | 3·7 „ | The whole a very putrid mass, but not mouldy. |
| | 110· cubic inches of carbonic acid, comprising 14·38 grains of carbon. | |

The putrid mass was brought to that state of dryness in which it was analysed, by desiccation, at 45° to 55°, over sulphuric acid. No carbonic acid was given off, neither was the acid darkened in colour. The dry mass weighed 45 grains, and was constituted of—

| | | |
|---|---|---|
| Carbon | 33·56 | 15·10 |
| Hydrogen | 6·70 | 3·02 |
| Oxygen | 37·32 | 16·79 |
| Nitrogen | 4·22 | 1·90 |
| Ashes | 18·20 | 8·19 |
| | 100· | 45· |

These give for the carbon in the—

| | | |
|---|---|---|
| Carbonic acid in the experiment, | 14·38 | grains. |
| Putrid body | 15·10 | „ |
| Total | 29·48 | |
| Fresh cabbage leaves | 42·9 | |
| Loss of carbon, | 13·42 | grains, |

equal to 31·3 per cent. upon that in the experiment at the commencement, independently of that contained in the 50 grains of putrid liquor; and that, in the carbonic acid in the atmosphere inclosed within the jar at each examination.

Another experiment was made with both the white and green part of the cabbage, and its object was not only to prove that carbon disappears during the putrefaction of this kind of matter, but also to show, that a large portion of matter soluble in cold water is formed. These cabbage leaves, which were first boiled in water, and afterwards washed and drained, were deprived of the principal part of their soluble matter. One portion of these boiled leaves, weighing 2,000 grains, were prepared for analysis, by drying at a temperature not exceeding 140°, and allowed to acquire the hygroscopic state of the atmosphere when their weight was 178 grains, and constituted of—

| | | |
|---|---|---|
| Carbon | 35·18 | 62·6 |
| Hydrogen | 6·12 | 10·9 |
| Oxygen | 50·42 | 89·8 |
| Nitrogen | 3·08 | 5·5 |
| Ashes | 5·20 | 9·2 |
| | 100. | 178· |

A similar portion, weighing 2,000 grains, was put along with 60 grains of putrid liquor, into a strong bottle, content 38 cubic inches. A small graduated tube was introduced, the bottle tightly corked down, and placed where the temperature was uniformly about 60°, where it stood from the 27th January to the 24th April. On drawing the cork, a portion of gas rushed out, and the remaining gaseous contents of the bottle contained 15 per cent. of its volume of carbonic acid. The vegetable substance appeared to be in a decaying condition. The experiment had lost 28 grains in weight.

The bottle was again tightly corked down, the cork sealed over, and placed in a shaded situation, in a green-house. The loss in weight, from the 24th April to the 9th June, was 9 grains, and from this date to the 5th December, 7 grains; making the total loss in weight 44 grains.

On removing the cork, there was no emission of gas; the atmosphere within the bottle contained 4·5 per cent. of its volume of carbonic acid. The whole mass was in a highly putrescent state, covered partly with blue, and partly with white mould:—a considerable portion of liquor, sp. gr. 1009·8 at 60°, had been formed. The contents of the bottle were cleaned out, and dried, at a temperature not exceeding 120°, when their weight was 58·6 grains, and constituted of—

| | | |
|---|---|---|
| Carbon | 40·6 | 23·81 |
| Hydrogen | 5·7 | 3·32 |
| Oxygen | 30·3 | 17·79 |
| Nitrogen | 6·6 | 3·89 |
| Ashes | 16·8 | 9·79 |
| | 100· | 58·6 |

From 45 to 50 per cent. of this dry powder was taken up by cold water, by stirring and shaking; the remainder appeared to be the tendril part of the plant principally, in an undecomposed condition.

On drawing a comparison between the weight of the carbon in this experiment, at the commencement and at the conclusion, we shall be over-rating that in the latter, by regarding the loss in weight, after drawing the cork on the 24th of April, to be carbon, in combination with organic oxygen; and the loss between this date and the 5th of December, to be carbon in combination with atmospheric oxygen, making the weight of carbon which passed off up to the 24th of April 10·12 grains, and that between April and December 16 grains. These give, for the weight of the carbon in the—

| | |
|---|---|
| Dry powder | 23·81 |
| In combination with organic oxygen | 10·12 |
| „ atmospheric do. | 16·00 |
| Total | 49·93 |
| In the undecomposed cabbage leaves | 62·6 |
| Loss of carbon | 12·67 grains, |

equivalent to 20·3 per cent.

The chemical changes which took place in this experiment, resemble those which occur when matter of this kind is laid up in heaps. A chemical action first takes place, without the agency of much atmospheric oxygen, and which has for one of its products carbonic acid; when this gas is prevented from escaping, it appears to undergo decomposition in a manner which more extended experiments must explain. Another important feature in this experiment, which has a practical application, is, the solubility of organic matter which was insoluble in either hot or cold water. A considerable portion of the cabbage leaves, which was insoluble in boiling water, was, by the putrefactive fermentation, rendered so soluble, that water at 60°, held in solution more than 2 per cent. of its weight of organic matter in a highly putrescent state. This solution, on being exposed to the atmosphere, gave off small portions of carbonic acid, accompanied with noxious effluvia.

## CARBON DISAPPEARS WHEN SEEDS FROM WHENCE OILS HAVE BEEN EXPRESSED UNDERGO PUTREFACTION.

50 grains (by weight) of cocoa-nut cake, in the condition in which it is employed as a fertilizer of land, and constituted of—

| | | |
|---|---|---|
| Carbon | 40·53 | 20·27 |
| Hydrogen | 7·91 | 3·95 |
| Oxygen | 42·30 | 21·15 |
| Nitrogen | 3·66 | 1·83 |
| Ashes | 5·60 | 2·80 |
| | 100· | 50· |

was placed in an open dish, and moistened with 200 grains of water. This dish was covered with a jar; content, 160 cubic inches; resting upon a plate, containing a portion of mercury, which cut off atmospheric communication. The experiment was kept at a temperature varying from 62° to 67°, for six weeks, during which time it was examined five times for carbonic acid, in the manner already described.

On the fourth day, the decaying body was covered with fungi; and on the eighth day, they were about an inch in length. On the fourteenth day, some of these fungi began to disappear, and were succeeded by a covering of blue mould. During the six weeks, a small portion of water was added three times. At the final examination, it was covered with a thin skin, supporting the mould: 76·7 cubic inches of carbonic acid was removed by liquor potassa, at the five different examinations. On drying the experiment over sulphuric acid, 2 cubic inches of carbonic acid was given off; making the entire volume 78·7 inches, comprising 10·18 grains of carbon. The putrid mass, when brought to that state of dryness at which it was analysed, weighed 22·4 grains, and was constituted of—

| | | |
|---|---|---|
| Carbon | 37·56 | 8·41 |
| Hydrogen | 7·82 | 1·75 |
| Oxygen | 34·53 | 7·73 |
| Nitrogen | 6·99 | 1·57 |
| Ashes | 13·10 | 2·94 |
| | 100· | 22·4 |

On comparing the weight of carbon in this experiment, at the two periods, we have—

| | | Grains. |
|---|---|---|
| At the conclusion | In the carbonic acid .. | 10·18 |
| | „ dry powder .... | 8·41 |
| Total | | 18·59 |
| At the commencement | | 20·27 |
| Shewing a deficiency of | | 1·68 |

equivalent to 8·3 per cent., without calculating for that in the atmosphere in which the experiment was conducted, which would make the deficiency about 12 per cent.

Common oil cake, when placed under a similar mode of experimenting, gave results which shewed a greater deficiency of carbon. The subject of the following experiment was bought in the market as linseed oil cake. It was constituted of—

| | |
|---|---|
| Carbon | 38·12 |
| Hydrogen | 7·60 |
| Oxygen | 43·12 |
| Nitrogen | 4·12 |
| Ashes | 7·04 |
| | 100· |

100 grains (in weight) of this cake, moistened at first with 400 grains of water, and afterwards at each examination with a little more, which kept it in a proper state of moisture for passing into decomposition, was kept within a glass shade, content 206 cubic inches, for seven weeks; atmospheric communication being cut off by mercury. During this period, it was examined six times, when 99·3 cubic inches of carbonic acid was removed; to which must be added 3·4 cubic inches for that given off during desiccation; making a total of 102·7 cubic inches, containing 13·42 grains of carbon. The partially dried putrid matter weighed 54·2 grains, and was constituted of—

| | | |
|---|---|---|
| Carbon | 33·76 | 18·30 |
| Hydrogen | 7·84 | 4·26 |
| Oxygen | 38·18 | 20·69 |
| Nitrogen | 5·12 | 2·77 |
| Ashes | 15·10 | 8·18 |
| | 100· | 54·2 |

These give—

| | Grains. |
|---|---|
| Carbon in the carbonic acid | 13·42 |
| „ „ putrid body | 18·30 |
| Total | 31·72 |
| Carbon in the oil cake | 38·12 |
| Deficiency | 6·40 |

equivalent to 16·8 per cent.

The putrefactive fermentation appears to fit these bodies for the service of plants, by rendering their parts more soluble in water. 40 grains of this partially dried putrid body yielded to water, at 60°, 23 grains of soluble compounds; while 80 grains of the undecomposed, yielded only 14·4 grains.

Other experiments, in which atmospheric communication was interrupted, but not cut off, were made with samples of these cakes. They were intended to show how quickly these bodies pass into decomposition, when mixed with the soil. They were kept in a moist state, and at a temperature varying from 55° to 75°.

| Experiment with | Weeks. | Loss in weight. |
|---|---|---|
| Cocoa-nut cake | 6 | 48 per cent. |
| Ditto, ditto | 13 | 70 „ |
| Oil cake | 6 | 54 „ |
| Ditto, ditto | 13 | 77 „ |

The rapid decomposition of such bodies, their copiously giving off carbonic acid, and the high degree in which they impregnate the surrounding atmosphere with ammonia and miasm; account satisfactorily for the more immediate, but less permanent fertilizing properties of this kind of organic matter, when compared with other bodies which do not pass so readily into decomposition.

In the ordinary operations of husbandry, the decomposition of these bodies is promoted by the increased temperature of the earth, occasioned by the sun's rays, when the plants have the power of removing carbonic acid and miasmatic odour from the atmosphere, and of appropriating them, by some mysterious process, to their own purpose. Their capacity for removing either is increased by the presence of the other. The fertilizing effect of putrefactive bodies appears to bear a proportion (within certain limits) to the rapidity of the putrefactive process, and to the quantity of carbonic acid, ammonia, and miasm, given off by the decomposing bodies.

## CARBON DISAPPEARS WHEN FERMENTED LIQUORS UNDERGO THE PUTREFACTIVE FERMENTATION.

The products resulting from the putrefactive fermentation of fermented liquors, do not contain the same weight of carbon which the liquors originally comprised. This loss of carbon appears to be sustained, both when the putrefactive process takes place under free exposure to the surrounding atmosphere, and when the liquors are kept in comparatively close vessels, such as corked bottles, &c. So, carbon disappears when small proportions of spirit are mixed with weak solutions of vegetable matter; and in this case, the disappearance of carbon during the putrefaction of the spirit and the vegetable matter, appears to be favoured by the mixture. Thus, when a small proportion of spirit is added to a weak solution of vegetable matter, which is disposed to pass slowly into the putrefactive fermentation, on keeping this mixture at the same temperature, the putrefactive process is, after a few days of comparative repose, accelerated. The putrefactive fermentation, and consequently the disappearance of carbon, in these liquors and mixtures of liquors, &c., is also favoured by the addition of other bodies already in a state of putrescence.

The preparation, conducting, and final examination of experiments, which come under this head, require great attention, nice discrimination, and accurate manipulation. The first to be described was made with 7,600 grains of malt wort; specific gravity, 1053·2 at 60°; composed of—

| | |
|---|---|
| Water | 6627 grains. |
| Dry vegetable matter | 973 „ |

The vegetable matter was constituted of—

| | | |
|---|---|---|
| Carbon | 44·1 | 438·1 |
| Hydrogen | 5·6 | 51·0 |
| Oxygen | 47·7 | 458·7 |
| Nitrogen | 1·3 | 12·6 |
| Ashes | 1·3 | 12·6 |
| | 100· | 973· |

Making the malt wort under experiment composed of—

| | |
|---|---|
| Carbon | 438·1 |
| Hydrogen | 787·3 |
| Oxygen | 6349·4 |
| Nitrogen | 12·6 |
| Ashes | 12·6 |
| | 7600· |

This solution of malt was put into a bottle, content 38·5 cubic inches, and into the neck of which was ground a tube, bent four times at right angles, and having a bore one-tenth of an inch in diameter generally; but from the last bend to the extreme end, the bore was three-tenths of an inch.

This malt-wort underwent a slow and imperfect vinous fermentation, during which 226 cubic inches of carbonic acid gas was given off in the first three months; at the expiration of which, the putrefactive fermentation had commenced. From this time, to the final examination of the experiment, the end of the bent tube was kept under an inch of mercury. The volume of air in the apparatus was about eight cubic inches, varying with the variation of temperature and atmospheric pressure. The rising and falling of the mercury, in the bent tube, with each of such change, indicated that the apparatus was air-tight; that no gaseous body escaped; and that external atmospheric communication was cut off.

When the experiment had stood from the 4th of May, 1836, to the 15th of October, 1839, it was examined, and found as under.

It had lost in weight ............ 141 grains.
The odour from the liquor was highly offensive.
Its sp. gr. at 60°, was.......... 1016·8 grains.
It contained little, or no carbonic acid.
„ „ of its weight of acetic acid ·03 per cent.
„ „ of Gilpin's alcohol .... 2·42 „

and on drying the whole mass, at a temperature not exceeding 120°, an acid semi-fluid was obtained, which weighed 374 grains, and was constituted of—

| | | |
|---|---|---|
| Carbon | 37·9 | 141·7 |
| Hydrogen | 6·7 | 24·5 |
| Oxygen | 50·7 | 190·2 |
| Nitrogen | 1·6 | 6·0 |
| Ashes | 3·1 | 11·6 |
| | 100· | 374· |

On bringing this semi-fluid to a state of dryness, without charing any part, it lost in weight 51 grs., and was then constituted of—

| | |
|---|---|
| Carbon | 141·7 |
| Hydrogen | 18·8 |
| Oxygen | 144·9 |
| Nitrogen | 6·0 |
| Ashes | 11·6 |
| | 323· |

The 226 cubic inches of carbonic acid would contain—

29·6 grains of carbon.
77·2 „ oxygen.
106·8

These give, for the loss of weight after the first three months, (141−106·8=) 34·2 grains.

The acetic acid in the experiment would weigh 2·2 grains; constituted of—

| | |
|---|---|
| Carbon | 1·1 |
| Hydrogen | ·1 |
| Oxygen | 1·0 |
| | 2·2 grs. |

the principal part of which was comprised in the semi-fluid above-mentioned: a small proportion only of it could pass off during desiccation, at the temperature employed.

The *Gilpin alcohol* would weigh 180·5 grains; constituted of—

| | |
|---|---|
| Carbon | 90·2 grs. |
| Hydrogen | 14·7 „ |
| Oxygen | 75·6 „ |
| | 180·5 |

On a recapitulation of the elements in these products, we have—

| | Carbon. | Hydro. | Oxygen. | Nitro. | Ashes. | Total. |
|---|---|---|---|---|---|---|
| Dry undecomposed vegetable matter, containing a little acetic acid...... | 141·7 | 18·8 | 144·9 | 6·0 | 11·6 | 323· |
| Carbonic acid gas.... | 29·6 | .. | 77·2 | .. | .. | 106·8 |
| Acetic acid ......... | 1·1 | 0·1 | 1·0 | .. | .. | 2·2 |
| Pure alcohol........ | 90·2 | 22·1 | 59·0 | .. | .. | 171·3 |
| Insalubrious water .. | .. | 773·6 | 6188·9 | .. | .. | 6962·5 |
| Oct. 15, 1839. Total | 262·6 | 814·6 | 6471·0 | 6·0 | 11·6 | 7565·8 |
| May 4, 1836. Total | 438·1 | 787·3 | 6349·4 | 12·6 | 12·6 | 7600· |
| Increase.... | .. | 27·3 | 121·6 | .. | .. | .. |
| Decrease .. | 175·5 | .. | .. | 6·6 | 1·0 | 34·2 |

These shew a decrease in the weight of the carbon, equal to 40 per cent.; an increase in that of the hydrogen upon that in the dry vegetable matter, equal to 53·5 per cent.; and an increase of oxygen upon that in the same, equivalent to 28·7 per cent. When the hydrogen, and the oxygen, which formed the water in the experiment, are taken into the calculation, then the increase upon the hydrogen is reduced to 3·35 per cent.; and that in the oxygen to ·45 per cent. The loss in the weight of the experiment, not accounted for, and which comprises 6·6 grains of nitrogen, and one grain of ashes, is 34·2 grains, equivalent to ·45 per cent. only.

If we calculate for one-half of this 34·2 grains (which is not satisfactorily accounted for), as pure carbon, we reduce the loss in the weight of this body, to 158·4 grains, as equivalent to 36·2 per cent.

As a proof that some of the carbon in the vegetable matter in this experiment, underwent decomposition, I may mention, that if all the vegetable matter which disappeared, had, by means of the vinous fermentation, passed into carbonic acid and alcohol, the loss in weight, by carbonic acid, would have been about 300 grains, and not 141, as was found to be the case; and that the weight of alcohol, found by distillation, would have been about 330 grains, or nearly twice the weight found in the liquor, at the conclusion of the experiment.

In the following experiment, made also of malt-wort, but differently conducted in some respects, we have a very considerable loss of carbon sustained in less than twelve months. The putrefactive fermentation, in this experiment, was induced by the addition of a small proportion of liquor, in a state of putrescence. The mixture, at 60° of temperature, was 1072, in sp. gr., and was composed of—

| | | |
|---|---|---|
| Dry organic matter.... | 1022 | grains. |
| Water .............. | 4978 | „ |
| Total...... | 6000 | |

The organic matter was constituted of—

| | | |
|---|---|---|
| Carbon .............. | 457·2 | grs. |
| Hydrogen ............ | 61·3 | „ |
| Oxygen .............. | 475·9 | „ |
| Nitrogen ............ | 7·9 | „ |
| Ashes................ | 19·7 | „ |
| | 1022· | |

And the experiment of—

| | | |
|---|---|---|
| Carbon.............. | 457·2 | grs. |
| Hydrogen .......... | 613·0 | „ |
| Oxygen ............ | 4902·2 | „ |
| Nitrogen ............ | 7·9 | „ |
| Ashes .............. | 19·7 | „ |
| | 6000· | |

On the 27th of January, the weight of this mixture was weighed in a glass bottle, content forty-four cubic inches, into which was ground a tube, eighteen inches long, twice bent at right angles, whose bore was one-tenth of an inch in diameter, and through which a communication was kept up, during the time the liquor was under experiment, between the decomposing mass and the external atmosphere.

The experiment was kept at a temperature not varying more than two degrees over or under 60°, until the 18th of April; from that period to the final examination, it stood in a green-house, where the sun shone upon it about eight hours in the day. During the first three months, the liquor underwent a very imperfect vinous fermentation, evidenced by small bubbles of gas passing through the fermenting body, and the formation of a scum at the top. At the expiration of this period, little or no gas appeared to be formed internally; and that scum, which had been the product of the vinous fermentation principally, began to change its appearance, and assume characters indicative of the putrefactive fermentation.

The loss which the experiment had sustained in weight was—

| | | |
|---|---|---|
| On the | 19th Feb. | 39 grains. |
| „ | 18th April | 80 „ |
| „ | 17th June | 116 „ |
| „ | 7th January | 147 „ |

On the 7th of January the bent tube, which contained a little liquor, was removed, and the experiment was finally examined. The effluvia was highly offensive. The flame of a taper on being introduced into the bottle was not extinguished: a light white substance about two-tenths of an inch in thickness covered the surface of the liquor: at the bottom of the bottle there was a considerable portion of light-coloured druggy matter. The liquor was opaque, had changed in colour from dark to light amber, was 1038·8 at 60° in specific gravity, contained 7 per cent. of its weight of acetic acid, but neither spirit nor carbonic acid.

A perfect mixture was made of the whole mass, and two portions were dried at temperatures not exceeding 125° and 130°. An acid semi-fluid was obtained from both, whose weights were, on calculating for the whole quantity; for that dried at and under 125°, 752 grains; and for that dried at and under 130, 749 grains.

On subjecting the two to ultimate analysis, the results in respect of carbon were slightly in favour of the latter. The former gave for the whole quantity, 251·2 grains of carbon. The latter was constituted of—

| | | |
|---|---|---|
| Carbon | 33·65 | 252·0 |
| Hydrogen | 6·83 | 51·2 |
| Oxygen | 57·30 | 429·3 |
| Nitrogen | ·32 | 2·4 |
| Ashes | 1·9 | 14·1 |
| | 100· | 749· |

The insalubrious water, obtained on testing for spirit by distillation, yielding no carbon by ultimate analysis, the temperature at which the thin semi-fluid was prepared, being such as would not volatilize the acetic acid, the above analysis may be regarded as representing the weight of carbon comprised in the experiment on the 7th January. And if to this analysis we add hydrogen and oxygen in the proportions in which they form water, to make up the weight, we have the experiment at the conclusion constituted of—

| | | |
|---|---|---|
| Carbon .......... | 252·0 | grains. |
| Hydrogen........ | 618·2 | „ |
| Oxygen ......... | 4966·3 | „ |
| Nitrogen ... .... | 2·4 | „ |
| Ashes .......... | 14·1 | „ |
| | 5853· | |

The loss in weight which the experiment sustained up to the 18th of April would, for the most part, be carbonic acid, carrying with it a proportion of the vapour of water not exceeding three per cent. On calculating for this loss as dry carbonic acid, the 80 grains would be constituted of

| | | |
|---|---|---|
| Carbon ............ | 22·1 | grains. |
| Oxygen ........... | 57·9 | „ |
| | 80· | |

The other 67 grains, making up the total loss in weight, would be composed partly of a small portion of carbonic acid gas, formed by the oxygen and carbon in the experiment; partly of carbonic acid gas formed by atmospheric oxygen combining with the carbon in the experiment; and partly of miasmatic vapour and ammonia in combination with water.

But that the loss of carbon in the experiment may appear in as disadvantageous a light as possible, we shall, on a recapitulation of these elements, call this loss in weight of 67 grains, pure carbon.

| | Carb. | Hydro. | Oxy. | Nitro. | Ash. | Total. |
|---|---|---|---|---|---|---|
| Putrid liquor | 252·0 | 618·2 | 4966·3 | 2·4 | 14·1 | 5853· |
| Carbonic acid | 22·1 | .. | 57·9 | .. | .. | 80· |
| Carbon making up loss in weight | 67·0 | .. | .. | .. | .. | 67· |
| Total | 341·1 | 618·2 | 5024·2 | 2·4 | 14·1 | 6000· |
| Original constitution | 457·2 | 613·0 | 4902·2 | 7·9 | 19·7 | 6000· |
| Increase | .. | 5·2 | 122·0 | .. | .. | .. |
| Decrease | 116·1 | .. | .. | 5·5 | 5 6 | .. |

Thus we find when the most unfavourable construction is put upon every part of the experiment, we have the results, giving a loss of carbon equivalent to 25 per cent., and it is probable that 40 per cent. is nearer the truth.

Without entering into detailed observations upon the disappearance of the whole quantity of carbon in these two experiments; it might be observed here, that, in the one first mentioned, we have evidence of its disappearing when in the state of carbonic acid, and in the other when in that of spirit.

At the final examination of the first, there were present 171 grains of alcohol, which would require for its formation by the vinous fermentation 164 grains of carbonic acid. The experiment when under the vinous fermentation furnished 226 cubic inches of this gas, which would weigh 107 grains, leaving a deficiency of 57 grains, equal to 120 cubic inches,—nearly four times the volume of the liquid under experiment. This is evidenced by the results of the experiment, independently of other carbon in the carbonic acid which would be formed at the same time, that other spirit would also be formed, and undergo decomposition in the manner evidenced in the second experiment. This second experiment, when under an imperfect vinous fermentation, lost 80 grains in weight, the principal part of which would be carbonic acid; and during its formation, 84 grains of alcohol would be formed, whose carbon appears to have undergone some change, as no spirit was found at the final examination of the experiment.

In the first of these experiments, the deficiency of carbon is equivalent to that in 223 grains of alcohol, and 213 grains of carbonic acid, the loss in weight by the experiment being only 141 grains. In the second experiment, in which no alcohol was found at the final examination, the deficiency of carbon was 116 grains, equivalent to that in 148 grains of alcohol, and 140 grains of carbonic acid; the loss in weight by the experiment being 147 grains.

The changes effected upon spirit, carbonic acid, and vegetable matter, during the putrefactive fermentation of dissolved vegetable bodies, also take place in some instances when weak ales, beer, and porter are kept under favourable circumstances for passing into this change. This is exemplified in the following experiments.

The two first were made of 5,850 grains each of amber-coloured malt liquor; specific gravity, at 60°, 1010·0. It contained—

2·59 per cent. of its weight of Gilpin's alcohol.
·25 „ „ „ acetic acid.
3·65 „ „ „ vegetable matter.
A small, but indefinite quantity of carbonic acid.

These give for the weight of carbon in each experiment, without calculating for that in the carbonic acid,—

| | | |
|---|---|---|
| In the Gilpin's alcohol | 75·7 | grains. |
| „ acetic acid | 7·4 | „ |
| „ dry vegetable matter | 93·7 | „ |
| Total | 176·8 | „ |

On the 28th May, 1836, these experiments were prepared, by putting this fermented liquor into flint glass bottles, into which were fitted ground stoppers. The bottles were about two-thirds full, and were kept in a room the temperature of which varied with the seasons, from 32° to 80°. During the first four months, a slight vinous fermentation went on in the one first to be described; this was followed by the putrefactive fermentation, evidenced by the light covering upon the top of the liquor, and by the formation of a white deposite. The stopper was never taken out of the bottle until the 15th January, 1840, the day on which it was examined.

The liquor was transparent and light coloured.
The bottle had lost in weight 29 grains.
The clear liquor contained 2·65 per cent. of its weight of Gilpin's alcohol.
The clear liquor contained ·35 per cent. of its weight of acetic acid.

On drying the entire mass, at a temperature not exceeding 110°, a semi-fluid was obtained, which weighed 75·8 grains, and which contained 33·54 per cent. of its weight of carbon. These give for the weight of the carbon in the experiment—

| | | | Grains. |
|---|---|---|---|
| 1836.—May 28 .. | Total weight of carbon .. | | 176·8 |
| 1840.—Jan. 15 | In Gilpin's alcohol.. | 77·2 | |
| | In acetic acid...... | 10·2 | |
| | In vegetable matter | 25·4 | |
| | | | 112·8 |
| | Deficiency of carbon ............ | | 64· |

equivalent to 36·2 per cent., which ought to be reduced, because a portion of the loss of 29 grains, which the experiment sustained in weight, would be carbon; to compensate for which we have, in the recapitulatory part of the process, all the carbon in the acetic acid calculated for at the conclusion of the experiment, both in the acetic acid and in the semi-fluid of which it would form a part, and have left out of the calculation that carbon in the undefined quantity of carbonic acid, contained in the experiment at the commencement.

The other experiment was prepared and conducted in a similar manner to the one described. It differed, however, in this respect, that whereas the former underwent a slight vinous fermentation, having for its products spirit and carbonic acid during the first four months, no such chemical change appeared to take place in this. In a few days after it was fitted up, it became covered with a white head, indicative of the putrefactive fermentation which appeared to be going on during the whole experiment. In Sept. 1840, it was finally examined, when it was found that the bottle had lost in weight 32 grains. The liquor was changed in colour from amber to light straw colour, was very transparent; it was covered with a thick white head, and a considerable quantity of white deposite was at the bottom of the bottle. There was no emission of gas on removing the stopper; but the miasm which proceeded from the liquor was offensive and sickening. The specific gravity of the clear liquor was 1004·3 at 60°. It gave no spirit by distillation, but a very offensive smelling liquor passed over, whose sp. gr. at 60° was the same as that of distilled water. It contained about one thousandth of its weight of acetic acid.

A perfect mixture was made of the whole mass; three different portions were brought to a state of semifluid, at temperatures not exceeding 110°, 120°, and 140°. These gave, for the whole quantity of carbon in the experiment, 51·4, 51·0, and 50·4 grains, which, on comparing with the weight of carbon originally contained in the experiment, gave—

| | | |
|---|---|---|
| May 1836 ........ | 176·8 | grains. |
| Sept. 1840 ........ | 51·4 | " |
| Deficiency.... | 125·4 | grains, |

On calling the 32 grains which the experiment lost in weight pure carbon, we reduce this deficiency to 93·4 grains, equivalent to 52·8 per cent.

Experiments upon different kinds of fermented liquors, made in corked bottles, about two-thirds filled, afforded very dissimilar results, on being kept, under similar circumstances, for six and seven years. Out of a set of nine experiments, made of pale ale, containing 4·2 per cent. of its weight of alcohol, and 3·4 per cent. of that of undecomposed vegetable matter, four only appeared to be affected by the putrefactive process; the rest increased, in a small proportion, their quantity of spirit, and diminished that of their vegetable matter. On a recapitulation of the products of these five, and calling the loss in weight, which the experiments sustained, pure carbon, we had an increase in the weight of this element upon that originally contained in the experiment. But on calling it one-fourth of this loss in weight, which, in all probability, is much nearer the correct estimate, then the gain or loss of carbon, shewn by the experiments, did not exceed the limits of error. The four experiments which appeared to undergo a putrefactive process, during the six years, gave results which represented the carbon:—

| | Without calling the loss in weight, of the experiment, pure carbon. | On calling this loss in weight, pure carbon. |
|---|---|---|
| No. 1, | 51·2 per cent. loss. | 14·8 per cent loss. |
| „ 2, | 42·5 „ „ | 10·6 „ „ |
| „ 3, | 34·6 „ „ | 5·4 „ „ |
| „ 4, | 24·1 „ „ | 8·8 „ gain. |

Of ten experiments, made of porter, containing 4·9 per cent. of its weight of alcohol, and 3·8 per cent. of that of undecomposed vegetable matter, prepared and kept, under similar circumstances, for ten years, three only appeared to pass into the putrefactive state. These gave results, which placed the carbon—

| | Without calling the loss in weight, of the experiment, pure carbon. | By calling this loss pure carbon. |
|---|---|---|
| No. 1, | 36,8 per cent. loss. | 10·2 per cent. loss. |
| „ 2, | 30·0 „ „ | 3·7 „ „ |
| „ 3, | 28·4 „ „ | .. .. .. |

The bottles in which these experiments were made, being about three-fourths full, the proportion which the liquor in them bore to their contents, corresponds with that in which fermented liquors in some instances lie in casks; and when the liquor loses so much in quality as a beverage. The chemical changes which took place in some of these experiments, are such as occur when such liquor as ale, and porter, lie at *ullage* in casks.

Unadulterated vinegar, when partially exposed to the atmosphere, is a good material for furnishing us with evidence of the decomposition of carbon and that of alkaline and earthy bodies; and in the usual manner of converting vinous fluids into vinegar, from one to three-fifths of the spirit undergoes the putrefactive fermentation, a considerable portion of its carbon undergoing decomposition.

These putrefactive changes are discoverable by a thin white film covering the surface of the liquor, which differs very materially in appearance from that which results from either the vinous or the acetous fermentation;—by the absence of internal commotion;—by a loss in colour in the upper strata of the liquor when compared with that of the lower,—the upper strata being also of less specific gravity, but of higher temperature;—by the original quantity of spirit being diminished in some instances, but not in all, and when this exception applies, the reduction in the specific gravity of the liquor is great, beyond what can be accounted for by the fermentation of the increased quantity of spirit;—by the absence of carbonic acid in the liquor, however much it originally contained:—and when the putrefactive fermentation has been continued for a long period, scarcely a trace of the earthy and alkaline bodies which the fermented liquor originally contained, can be discovered in either the liquor, or in the deposite which has been formed.

I may conclude this imperfectly investigated subject, by saying, that so far as my experiments extend, the disappearance of carbon during the putrefactive fermentation of organic matter is universal; the proportionate quantity which disappears varying with the character of that process, which, unlike the vinous or the acetous fermentation, assumes at least twenty different characters, each having products peculiar to itself.

These different forms of the putrefactive fermentation, I cannot attempt accurately to describe. I would only remark, that, in them all, the compound nature of carbon is evidenced, as well by its own disappearance, as by the increased quantity of hydrogen and oxygen, and the presence of miasm;—that the increase of hydrogen, when compared with the increase of oxygen, is generally, if not always, in a higher proportion than that in which they form water;—that miasm is a body highly endowed with power to favour or induce that chemical action by which it is formed;—that each putrefactive process has its own miasmatic product, differing in some respects, but all agreeing in their intimate connection with hydrogen. And I might add here, that my observations during the whole course of my experiments, have led me to the conclusion that, of the elements, carbon, hydrogen, oxygen, nitrogen, sodium, potassium, calcium, &c. which constitute the organic and inorganic parts of plants, hydrogen is the only ultimate element, the rest being all compound bodies; and to question the compound nature of hydrogen.

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